OBSERVING AND OVERCOMING REDUCED RIGHT HEMISPHERE INVOLVEMENT IN SPATIAL ATTENTION IN ADULTS WITH AUTISTIC-LIKE TRAITS

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Bachelor of Science (Honours)

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THESIS DECLARATION

I, Michael Charles Woodfield English, certify that:

This thesis has been substantially accomplished during enrolment in the degree.

This thesis does not contain material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution.

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The research involving human data reported in this thesis was assessed and approved by The University of Western Australia Human Research Ethics Committee. Approval number(s): RA/4/1/6140, RA/4/1/7383 and RA/4/1/5247.

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Signature: [Redacted]  Date: 07 April 2017
ABSTRACT

Individuals with autism spectrum conditions (ASC) show a reduced preference for coherent, globally-organized visual stimuli, as demonstrated by superior performance on tasks where attention must be directed towards local details, such as locating a simple shape (e.g. a triangle) hidden within a complex structure (e.g. a grandfather clock) (Muth et al., 2014). This behaviour is also shown by neurotypical individuals with high levels of autistic-like traits as assessed by the Autism-Spectrum Quotient (High AQ) relative to those with low levels of such traits (Low AQ) (Cribb et al., 2016). Given that global and local processing are generally attributed to right (RH) and left hemisphere activation respectively (Ivry & Robertson, 1998), a reduced drive for global processing associated with autism may be symptomatic of relatively reduced RH activation for spatial attention.

Pseudoneglect – over-attention to the left-side of visual space by neurotypical individuals – is thought to be driven by RH specialization for spatial attention, and therefore may be reduced in individuals with ASC or High AQ, similar to how left neglect arises following RH damage (Heilman et al., 2003). Several studies suggest that leftward attentional bias is also reduced for individuals with ASC, but these studies have used face stimuli in their designs (e.g. Dundas et al., 2012), and reduced activation of face-specific regions might account for these effects. Whether attentional biases for non-face stimuli are similarly affected is relatively unknown, and the possibility remains that pseudoneglect may be reduced for visual stimuli more broadly, consistent with a wider-ranging link between ASC and relatively reduced RH activation for spatial attention.

The present thesis comprises four experimental studies that aim to present new evidence on whether reduced RH activation for spatial attention characterises individuals with High AQ relative to their Low AQ counterparts, and to explore whether increasing RH activation can influence distribution of spatial attention. Given similarities in attentional profiles between individuals with ASC and those with High AQ, investigating the spatial performance of individuals differing in levels of autistic-like traits is a useful means of providing insight into ASC with the benefit of access to larger samples, while avoiding complexities associated with clinical ASC, like comorbid diagnoses (Landry & Chouinard, 2016).

Study 1 recruited a large sample (n=277) of university students, and found that High AQ participants, relative to Low AQ participants, showed reduced pseudoneglect
on a greyscales task, suggesting that RH activation of spatial attention was reduced for these individuals. Study 2 replicated this finding in another large student sample (n=104), and observed similar effects for a landmark task. However, pseudoneglect was found to be intact for High AQ individuals on a mental number line bisection task. Thus, the mechanism responsible for reduced pseudoneglect in the other tasks is likely to be linked to mechanisms related specifically to the visual system.

In Study 3 (n=200), a continuous performance attentional task (CPT) that specifically engages the RH (Degutis & Van Vleet, 2010) was successful at: 1) increasing attention directed towards global aspects of hierarchical Navon figures in neurotypical individuals even when participants were tasked with categorizing the local aspects, replicating earlier results (Van Vleet et al., 2011), and 2) extending these training benefits to individuals with High AQ. This training effect is a desirable result that encourages further investigations of whether CPT can improve processing of other stimuli amenable to global processing, like faces. In Study 4 (n=38), non-invasive, excitatory transcranial direct current stimulation over the right posterior parietal cortex (PPC) increased pseudoneglect on the greyscales task relative to a sham condition that delivered no stimulation for a High AQ group. Identical stimulation on a Low AQ group produced no such changes. These findings provide direct evidence that reduced right PPC activation contributes to reduced pseudoneglect in High AQ.

In conclusion, Study 1 and 2 provide novel evidence for reduced RH activation of spatial attention for individuals with High AQ, and that reduced pseudoneglect may be representative of a potentially new phenotypical expression of autism. The findings of Study 3 and 4 are perhaps even more important, highlighting that some atypical aspects of attention associated with autism are not necessarily fixed. Overall, the results of the reported studies further our understanding of attention in autism, and hopefully encourage further investigation into spatial attention and the specific involvement of the RH in the disorder.

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There have been many occasions over the last few years when I have sat at the computer, staring at the flashing cursor of a Word document while I wonder how to begin the next paragraph or section. This is usually followed by ten or so attempts at typing a first sentence in which I am satisfied that the weight of the words carry the meaning and impact I wish to impart to the reader. The section you are reading now has been by far one of the most difficult, because there are so many ways to begin, so many people to recognise, and so much gratitude and thanks to convey.

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CO-AUTHORED PUBLICATIONS

This thesis contains work that has been published and/or prepared for publication.

Chapter Two


The student designed the study, collected and analysed the data, and was the primary contributor on the manuscript.

Chapter Three


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Chapter Four


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Chapter Five

English, M. C. W., Kitching, E. S., Maybery, M. T., & Visser, T. A. W. (under review). Modulating attentional biases of adults with autistic traits using transcranial direct current stimulation.

This manuscript is under review with *Autism Research*.

The student designed the study, shared data collection with ESK, analysed the data, and was the primary contributor on the manuscript.

Date: _07 April 2017_

I, Troy Visser, certify that statements regarding their contribution to each of the works listed above are correct.

Coordinating supervisor signature: __________ Date: _07 April 2017_
OTHER WORK GENERATED DURING THE

CANDIDATURE

Research Articles


Conference Presentations

Individuals with autistic-like traits show reduced lateralization on a greyscales task (Chapter Two), presented at the Australasian Society for Autism Research 2014 and the Australian Experimental Psychology Conference 2015.

Threatening faces fail to guide attention for adults with autistic-like traits, presented at the Asia Pacific Conference on Vision 2016.

Atypical lateralization of attention in adults with autistic-like traits (Chapters Two, Three and Five), presented at the Australasian Society for Autism Research 2016. Prize winner for Best Student Presentation.
A NOTE ABOUT THE FORMAT OF THIS THESIS

This thesis was constructed using the “thesis as a series of papers”, or “thesis by publication” format that is increasingly used by PhD students in Australia as opposed to the traditional monograph. The thesis begins with an introductory chapter that provides an overview of the key aims of the thesis. These aims are then tackled in the following four chapters, each of which is a self-contained research article that underwent peer-review and was published during the candidature. The thesis then concludes with a broader discussion that synthesizes the findings of each of the prior chapters together.

While each “experimental” chapter is logical progression of the prior chapter, these pieces of work were also written to stand as independent articles. As such, the thesis is akin to a scientific research volume that has received input from many authors. Like these books, each chapter in the thesis begins with an overview of research pertinent to the current chapter and while some of the literature may have been raised earlier in the thesis the reader can be assured that the current chapter can be comprehended without having read prior chapters.

Due to the different types of manuscripts that form each of these chapters there is some variation in chapter length. The manuscripts that Chapter Two and Five are drawn from are Brief Reports, whereas Chapter Three and Four are based on traditional Articles, and are considerably longer.

Finally, to maintain consistency between the published and thesis versions of each piece of work, the research articles presented in the thesis entirely unchanged save for formatting changes. However, where examiners made suggestions for additions or changes to the work, these comments are addressed in footnotes (which are naturally absent in the published version).
CHAPTER ONE

General Introduction

Behavioural performance on attentional tasks can often provide insight into underlying cortical processes. In this thesis, several studies are outlined that a) provide novel evidence for reduced right hemisphere activation for visuospatial attention in individuals with high levels of autistic-like traits and, b) demonstrate that techniques that increase right hemisphere activation can modulate aspects of attention in these same individuals such that they perform more comparable to their low-trait peers. The current chapter is a review of the literature pertinent to the present thesis, providing an overview of autism and autistic-like traits, how visuospatial ability manifests in the context of autism, and the role of the right hemisphere in visuospatial attention. Finally, the chapter highlights how studies investigating the possibility of reduced right hemisphere activation for visuospatial attention by individuals with high levels of autistic-like traits may expand our current understanding of attention in autism.

Autism

Symptoms

The term “autism” was first used by psychiatrist Leo Kanner (1943) in a paper where he described his observations of 11 children whose specific patterns of abnormal behaviour, interests and social ability did not fit any diagnosis available at the time. The diagnostic criteria for autism have undergone several changes since Kanner’s description, with the condition currently defined in the Diagnostic and Statistical Manual of Mental Disorders – Fifth Edition (DSM-5) as a
neurodevelopmental disorder that is primarily characterized by repetitive and restrictive patterns of behaviour and interests, and impairments in communication and social functioning (American Psychiatric Association, 2013). However, while research into autism has steadily increased, our understanding of its exact nature and causal factors are still limited.

Repetitiveness may be demonstrated in several modalities; from simple motor movements (e.g. hand flapping, body rocking) and speech (echoing others, repeating simple phrases), to routines and rituals (walking the same route to school, sitting in the same chair every day). Repetitive behaviours are often accompanied by a strong instinct for sameness, and individuals are inflexible with change or deviation from their desired patterns and rituals. Extreme distress is usually displayed when completing a behaviour in the desired manner is blocked. Autistic individuals show restricted interests and fixate on objects or ideas with uncommon intensity (e.g. needing to know what caused a crack in the ceiling), and distress is again displayed when engaging in a special interest is impeded. Socially, autistic individuals fail to develop many fundamental skills, showing difficulty with conversational turn-taking, avoiding eye-contact and making limited use of non-verbal communication. Individuals with the condition also have deficits in the ability to share in others interests when they are not personally held and difficulty with adapting to different situations to suit the context or mood. These limitations typically result in failure to develop and maintain close relationships.

Subtypes

As research into autism progressed, references to several different ‘sub-types’ based on variability and severity of the symptoms became more common in the literature. Often referred to, but not present within current diagnostic manuals, is a distinction between "low-functioning" and "high-functioning" autism\(^1\). Low-functioning autism is generally characterized by the additional presence of an intellectual disorder, and individuals with this designation demonstrate the most extreme levels of symptom severity and are unlikely to gain the ability to live independently. In contrast, those described with "high-functioning" autism exhibit largely intact cognitive abilities and can function with a degree of independence. Under the previous incarnation of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV), Autistic Disorder was

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\(^1\) While the terms low- and high-functioning autism are commonly used in the literature, it should be noted that these terms are currently at odds with current practice in describing autism and the movement towards more neurodiverse language.
supplemented by two further categories – Asperger’s Disorder and Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS) (American Psychiatric Association, 2000). Though in the current DSM-5 these diagnoses have since been folded into a single diagnosis of Autism Spectrum Disorder (American Psychiatric Association, 2013), the former terms are still commonly used today (and indeed variants of them currently exist within the current, 10th revision of the International Statistical Classification of Diseases and Related Health Problems (World Health Organization, 1992)). Previously, some “high-functioning” individuals may have received a diagnosis of Asperger’s Disorder if they met two of the three primary diagnostic criteria for Autistic Disorder, but their language development was not impaired or delayed (American Psychiatric Association, 2000). A diagnosis of PDD-NOS was made if individuals exhibited several key symptoms associated with Autistic Disorder, but did not show enough symptoms with the severity required for a specific diagnosis (American Psychiatric Association, 2000).

In this thesis, I follow the example set by Simon Baron-Cohen (2009) and will refer to the family of diagnostic categories as autism spectrum conditions (ASC). This term serves two functions: first, ‘condition’ is less stigmatising than ‘disorder’ and, second, the term recognises that while autistic individuals have disabilities, they are also not without cognitive strengths, which will be discussed later.

Prevalence

A recent review estimated that, globally, ASC affects approximately 62 individuals in every 10,000, though minimal data regarding prevalence rates is available from many low- and middle-income countries (Elsabbagh et al., 2012). In Australia, the latest estimates indicate that ASC was reported in some form in 115,400 (0.5%) individuals (Australian Bureau of Statistics, 2012). While males are significantly more likely to receive an ASC diagnosis, estimates of the exact male-to-female ratio vary substantially. Across the full intelligence quotient range, ASC is more common in males at a ratio of 4.3:1 (Fombonne, 2003, 2005), but among those without co-occurring intellectual disabilities, the ratio ranges from 5.75:1 to 16:1 (Baird et al., 2006; Fombonne, 2003, 2005; Scott, Baron-Cohen, Bolton, & Brayne, 2002). Further complicating matters are suggestions that ASC is currently under-reported in females (Attwood, 2006; Constantino, 2011; Dworzynski, Ronald, Bolton, & Happé, 2012; Gillberg, 2005; Goldman, 2013). The large body of research using predominantly male samples (Thompson, Caruso, & Ellerbeck, 2003), and clinical tools that focus on externalized behaviours rather than the internalizing problems that are more common
in females (Giarelli et al., 2010; Mandy et al., 2012; Solomon, Miller, Taylor, Hinshaw, & Carter, 2012) may contribute towards potentially inflated reporting of sex ratios (for reviews, see: Kreiser & White, 2014; Lai, Lombardo, Auyeung, Chakrabarti, & Baron-Cohen, 2015).

Although the reported prevalence of ASC diagnoses has increased over several decades, it is unknown if actual prevalence of the disorder has changed since diagnostic categories and criteria have been updated, screening methods have improved and there is increased public awareness of autism (Hill, Zuckerman, & Frombonne, 2014; Karapurkar, Lee, Curran, Newschaffer, & Yeargin-Allsopp, 2004; Newschaffer et al., 2007; Wing & Potter, 2002). All of these changes increase the likelihood of an individual receiving an ASC diagnosis today when she/he would have been left undiagnosed in the past.

ASC and the neurotypical population

Genetic Origins of ASC

In his formative paper, Kanner (1943) noted that many of the parents of children examined in his study provided very detailed diaries, painting a picture of parental obsessiveness. He also observed that ‘warm-hearted’ mothers and fathers’ were few, and that many family members were more preoccupied with “abstractions of a scientific, literary, or artistic nature, and limited in genuine interest in people” (p. 250). These observations, in conjunction with studies on the effects of social deprivation in monkeys (Harlow & Harlow, 1962) and developments in mother-child attachment theories (Bowlby, 1951), led to the concept of “refrigerator mothers”; the notion that autism was caused by a lack of maternal warmth (Kanner, 1949). What Kanner may have unknowingly touched upon was a genetic factor in autism, which might have explained why many of the parents he interviewed showed milder forms of some of the characteristics present in their children. Unfortunately, the “refrigerator mother” account of autism persisted until Folstein and Rutter’s (1977) seminal finding that the concordance rate for autism was significantly higher between monozygotic twins than between dizygotic twins. A recent meta-analysis of the twin studies that have ensued since then indicates that heritability estimates are in the range of 64-91% (Tick, Bolton, Happé, Rutter, & Rijsdijk, 2016).

Autistic-like traits

Since the genetic basis of ASC was established, many studies have compared healthy individuals with immediate ASC relatives to those without as to their
personality traits and other characteristics. Features such as rigid personalities and obsessiveness (Bolton, Pickles, Murphy, & Rutter, 1998; Demir, Demir, Albayrak, Kayaalp, & Dogangun, 2009; Lainhart et al., 2002; Piven, Palmer, Landa, et al., 1997), social reticence or aloof dispositions (Bolton et al., 1994; Murphy et al., 2000), fewer and less reciprocal relationships (Lainhart et al., 2002; Piven, Palmer, Jacobi, Childress, & Arndt, 1997), language abnormalities (Ben-Yizhak et al., 2011; Bishop et al., 2004; Landa et al., 1992; Le Couteur et al., 1996; Pickles et al., 2000; Piven, Palmer, Jacobi, et al., 1997; L. J. Taylor et al., 2013; Whitehouse, Coon, Miller, Salisbury, & Bishop, 2010), and deficits in theory of mind (Nagar Shimoni, Weizman, Yoran, & Raviv, 2012) have all been reported with higher rates in relatives of individuals with ASC compared to control groups, and produce an overall profile that is qualitatively similar to ASC (for review, see Pisula & Ziegart-Sadowska, 2015 and Sucksmith, Roth, & Hoekstra, 2011). This pattern of milder autistic-like traits is commonly referred to as the Broader Autism Phenotype (for review, see Ingersoll & Wainer, 2014).

Several attempts have been made to develop psychometric measures that can quantify the degree of autistic-like traits that an individual possesses. One of the first developed is the Autism Family History Interview (AFHI; Bolton et al., 1994), a standardized clinical interview which asks questions of ASC individuals and their immediate family members with respect to personality traits and behaviours in areas that are relevant to ASC, such as circumscribed interests, rigidity, perfectionism, obsessions and compulsions. Interviews are recorded, and blind raters determine the extent to which interviewee’s responses are qualitatively similar to the ASC behavioural profile.

While structured interviews such as the AFHI are effective tools for identifying ASC-like behavioural profiles in immediate relatives of individuals with ASC (Piven, Palmer, Jacobi, et al., 1997), the lengthy administration process led to the development of more accessible measures. A commonly-used scale is the 50-item self-report Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). The AQ can be likened to the AFHI, in that both can be used to measure autistic-like traits in healthy, neurotypical individuals, but the self-report nature and simple four-point Likert scale format of the AQ has driven increasing use of the measure since its inception. Similar to the AFHI, items on the AQ tap into key aspects of ASC (e.g. the item “I would rather go to a library than a party” is related to social functioning). Responses to statements are made using a four-point scale labelled “Strongly Disagree”, “Slightly Disagree” “Slightly Agree” and “Strongly Agree”. Baron-Cohen et al. (2001)
recommended dichotomous (0-1) scoring of responses, leading to an overall index ranging from 0-50, where higher scores indicate greater levels of autistic-like traits. Since the dichotomous scoring method does not distinguish between "strongly" or "slightly" agreeing/disagreeing with a statement, an alternative “1-4” method that distinguishes these responses, resulting in an index of 50-200, is often used instead (Austin, 2005).

Parents of children with ASC are reported to have higher AQ scores (more autistic-like traits) than parents with typically developing children (Bishop et al., 2004; Wheelwright, Auyeung, Allison, & Baron-Cohen, 2010; Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005), and twin studies observing levels of autistic-like traits in children show moderately similar heritability estimates to those reported for autistic children, ranging between 36-87% (for a review, see Ronald & Hoekstra, 2011). Furthermore, higher AQ scores are also associated with other measures of social functioning, such as reduced explicit and implicit knowledge of nonverbal cues (Ingersoll, 2010) and greater tendencies towards obsessional personality (Kunihira, Senju, Dairoku, Wakabayashi, & Hasegawa, 2006). Observations of autistic-like traits and behaviours in both individuals with and without immediate relatives with ASC has led to the conceptualization of autism as a continuum that extends beyond those with clinical diagnoses and into the neurotypical population (Constantino & Todd, 2003; Lundström, 2012; Posserud, Lundervold, & Gillberg, 2006; Ruzich et al., 2015) where AQ scores are reported to be normally distributed (Baron-Cohen et al., 2001; Hoekstra, Bartels, Verweij, & Boomsma, 2007).

The autism-as-a-continuum notion has allowed for the expansion of autism-related research into the broader neurotypical population, and a recent literature review identified over 870 studies that had used the AQ (Ruzich et al., 2015), suggesting that a substantial number of researchers believe that the examination of individuals with high levels of autistic-like traits is a valuable method of furthering our understanding of ASC. There are several benefits to conducting such studies (Landry & Chouinard, 2016), such as the ease of recruiting neurotypical volunteers, making it easier to test large sample sizes, and the fact that potential confounds, such as IQ, are more easily controlled for with neurotypical samples. One method by which these studies are conducted is by examining how task performance correlates with AQ scores in an unselected sample, such as a young adult student sample (i.e. the AQ scores for the sample would be expected to be normal in distribution). Alternatively, participants may be selectively recruited, based on their AQ scores, to create distinct comparison
groups (i.e. “Low” vs “High” AQ groups). This latter method has the advantage of paralleling the methodology of clinical studies, where group comparisons are similarly made between groups differing substantially on the autism continuum, that is, neurotypical and ASC samples.

However, the use of AQ-selected groups as a proxy for ASC/non-ASC groups is not without its critics. Gregory and Plaisted-Grant (2013) argued that differences between Low and High AQ groups may be in part due to undiagnosed, or otherwise unidentified, individuals with ASC included in the High AQ group. Consequently, AQ-based studies are ASC/non-ASC comparisons, and not true Low AQ/High AQ comparisons. Whilst the relatively low prevalence of ASC means it is unlikely that any High AQ group will be comprised of a significant proportion of unidentified individuals with ASC (Australian Bureau of Statistics, 2012), it is possible to reduce the impact of any ASC influence within High AQ groups. For example, recruiting particularly large samples can minimise the impact of any individual participant, and analyses can be conducted with and without the participants with the highest AQ scores (who are most likely to be unidentified individuals with ASC). As a result, Gregory and Plaisted-Grant's (2013) concerns can be addressed and the usefulness of the AQ as a research tool is retained.

**Weak Central Coherence Theory of Autism**

Conceptualisation

Though ASC is primarily characterised by a specific collection of impairments, there exists several domains in which individuals with ASC excel. Kanner (1943) was, again, the first to take note of some of these skills, observing that the children who were verbal had “astounding” vocabulary, “excellent” memory for events that had occurred in years past, and "phenomenal" rote memory for poems, names and other complex patterns and sequences (p. 247). Kanner also noted that these children had an inability to “experience wholes without full attention to the constituent parts” (p. 246). This latter behaviour is in sharp contrast to the usual focus of their typically developing peers on "wholes".

The innate drive for coherence in neurotypical individuals is a notion that dates back to the Gestalt movement, instigated by the suggestion that humans perceptually organise stimuli in a top-down manner, thus interpreting ‘the whole’ before attending to ‘the parts’ (Wertheimer, 1924/1938a). This 'global coherence' can be demonstrated by gestalt grouping principles; neurotypical individuals tend to automatically group
objects according to principles such as proximity, similarity and/or closure (Wertheimer, 1924/1938b). For example, grouping by proximity is shown in a configuration such as ‘... ... ...’, which is generally interpreted as three ellipses, rather than nine periods. The drive for coherence over detail is not limited to the visual domain. In a series of experiments where participants were tasked with remembering and recounting verbal material, Bartlett (1932) noted that participants tended to provide the gist and “general impression of the whole” when recounting, and from this they would “construct the probable detail” as a process secondary to recall of meaning (p. 206).

Frith (1989) expanded upon Kanner’s observations and suggested that both the deficits and “islets of ability” in ASC could be accounted for by a deficiency in global processing and weaker drive for coherence. This account became known as the weak central coherence (WCC) theory of autism, and is often generalised to suggest that a global processing deficit exists in individuals with ASC. Frith argued that because of impairments in the ability to construct a coherent whole, individuals with ASC showed superior performance on tasks that benefited from greater attention to detail, such as the Embedded Figures Test (EFT; Witkin, 1971) and Block Design subtest of the Wechsler Intelligence Scales (Wechsler, 2014), compared to neurotypical individuals (Kolinsky, Morais, Content, & Cary, 1987; Shah & Frith, 1983). In the EFT, participants are required to locate a simple shape (e.g., a triangle) that is embedded in a larger, complex picture (e.g. a grandfather clock). WCC suggests that performance is inversely related to the drive for coherence; those with an automatic tendency for integrating the details into a cohesive whole, which is most neurotypical individuals, have difficulty accessing details due to interference from the larger configuration. However, individuals with ASC do not exhibit the same drive for coherence and therefore have greater access to the details, resulting in faster reaction times by this group.

Performance on the Block Design test operates similarly. Participants must recreate a pattern using multiple blocks that have coloured squares or triangles on their faces. The pattern is seen as a cohesive whole by neurotypical participants, rather than multiple segments which would aid in locating the necessary blocks. Under the WCC theory of autism, ASC participants are less influenced by the whole, and so are able to locate the blocks required to reproduce the pattern faster (Shah & Frith, 1983). Consistent with this position, if the pattern to-be-copied is pre-segmented, neurotypical participants show marked improvement in reaction times, whilst ASC participants are unaffected (Shah & Frith, 1993). Conversely, WCC also explains why
individuals with ASC perform worse on tasks that have a greater emphasis on integrating multiple independent stimuli. For example, in a study in which children had to remember a pattern of coloured counters (Frith, 1970), typically developing children quickly learned the overall pattern and often exaggerated it. On the other hand, children with ASC used only the most recent counters to guess the colour of the next instead of using the overall pattern structure, and consequently performed worse on the task.

**Mixed support for Weak Central Coherence**

Since Frith’s original account, subsequent research has tested the extent to which the WCC theory holds. One of the most prevailing findings, the superior performance on the EFT by individuals with ASC, has been replicated many times (Brosnan, Gwilliam, & Walker, 2012; De Jonge, Kemner, & Van Engeland, 2006; Edgin & Pennington, 2005; Falter, Plaisted, & Davis, 2008; Jarrold, Gilchrist, & Bender, 2005; Jolliffe & Baron-Cohen, 1997; Keen et al., 2009; Morgan, Maybery, & Durkin, 2003; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005; Pellicano, Maybery, Durkin, & Maley, 2006; Ropar & Mitchell, 2001; Schlooz & Hulstijn, 2014; Van Lang, Bouma, Sytema, Kraijer, & Minderaa, 2006). A similar pattern is also seen when comparing neurotypical individuals who have low- or high-levels of autistic trait as measured by the AQ, with a recent meta-analysis (Cribb, Olaith, Di Lorenzo, Dunlop, & Maybery, 2016) showing that High AQ groups reliably have superior performance on the EFT relative to Low AQ groups. Not all studies have supported the WCC theory, with several studies finding comparable EFT performance between neurotypical and ASC groups (Bölte, Holtmann, Poustka, Scheurich, & Schmidt, 2007; Chen, Lemonnier, Lazartigues, & Planche, 2008; Dillen, Steyaert, Op de Beeck, & Boets, 2015; Kaland, Mortensen, & Smith, 2007; Ovono, Pennington, & Rogers, 1991; Pring, Ryder, Crane, & Hermelin, 2010; Schlooz et al., 2006; Spek, Scholte, & Van Berckelaer-Onnes, 2011; L. J. Taylor, Maybery, Grayndler, & Whitehouse, 2014; White & Saldaña, 2011) and, occasionally, superior performance in ASC groups (Burnette et al., 2005; Spek et al., 2011).

With respect to the Block Design test, several studies have also replicated Shah and Frith’s (1983) initial observations (Happe, 1994; Morgan et al., 2003; Pellicano et al., 2006; Pring, Hermelin, & Heavey, 1995; Ropar & Mitchell, 2001; Soulères, Zeffiro, Girard, & Mottron, 2011), and identical patterns have also been reported in studies using neurotypical individuals with autistic-like traits, where individuals with High AQ outperforming those with Low AQ (Grinter et al., 2009; Stewart, Watson, Allcock, & Yaqoob, 2009). Despite some conflicting findings, a recent meta-analysis found that,
overall, individuals with ASC generally show superior performance on both the EFT and Block Design test (Muth, Hönekopp, & Falter, 2014).

Moving beyond the initial tasks used by Shah and Frith, differences between ASC and control individuals have also been noted using hierarchical Navon figures (Navon, 1977), likely due to the similar properties that these figures share with stimuli in the EFT. A Navon figure (illustrated in Figure 1.1) consists of multiple, small characters (local level) that make up the shape of a single, larger character (global level). Most variations of tasks that use Navon figures require participants to attend and respond to either the global or local level of the figure, whilst ignoring the other level (e.g. categorize the global level character as a number or a letter). Optimum task performance is generally achieved when the two levels are congruent (e.g. the first two examples of Figure 1.1 share the same global and local level category). However, performance can be impaired when the two levels are incongruent (e.g. the last two examples of Figure 1.1 do not share the same global and local level category), and the amount of interference from the to-be-ignored level provides insight into participant’s attentional preferences.

When neurotypical individuals are directed to categorize the global level as a letter or number, task reaction times are typically not significantly impaired when the local level is incongruent to the global level relative to reaction times for stimuli with congruent global and local features. However, when categorizing the local level, the presence of global features that are incongruent significantly increases reaction times relative to occasions when the global features are congruent, demonstrating that the drive for coherence is present even when it is irrelevant to the current task and results in sub-optimal performance. In contrast, individuals with ASC do not demonstrate as great a level of global interference as neurotypical individuals, instead showing greater interference from local features (Behrmann et al., 2006; Gross, 2005; Mottron & Belleville, 1993; Plaisted, Swettenham, & Rees, 1999; Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2000; L. Wang, Mottron, Peng, Berthiaume, & Dawson, 2007).
Similar to the EFT, a number of studies report conflicting findings when using Navon figures, showing a lack of evidence for greater local processing biases in ASC groups relative to controls (Iarocci, Burack, Shore, Mottron, & Enns, 2006; Mottron, Burack, Iarocci, Belleville, & Enns, 2003; Mottron, Burack, Stauder, & Robaey, 1999; Ozonoff, Strayer, McMahon, & Filloux, 1994; Plaisted et al., 1999; Rinehart et al., 2000; Rondan & Deruelle, 2007; L. Wang et al., 2007). Only two studies have investigated the effects of AQ on performance where hierarchical figure stimuli have been used. The first revealed no difference between High- and Low AQ groups (Sutherland & Crewther, 2010), but in the second, which employed a non-conscious cueing paradigm, High AQ individuals demonstrated a cueing effect of smaller local-level cues in hierarchical arrow stimuli, whilst Low AQ individuals showed cueing effects from the global-level of the stimuli (Laycock, Chan, & Crewther, 2017).

In response to these conflicting findings, a recent meta-analysis was conducted that encompassed 56 studies assessing visual global and local processing in ASC (Van der Hallen, Evers, Breweaes, Van den Noortgate, & Wagemans, 2015). The authors of the meta-analysis found that, in terms of overall accuracy, there is neither enhanced local processing nor deficits in global processing. However, the analysis also showed that global processing is slowed in individuals with ASC, especially on tasks where participants have to attend to globally-presented targets whilst ignoring distractors presented at the local level, suggesting that local-to-global interference is present within individuals with ASC. The authors suggest that this finding partially supports the WCC theory, and that future research should focus on the processes and mechanisms that underlie perceptual functioning in ASC, rather than mere ability and inability.
Perceptual Mechanisms Underlying ASC: Attention and the Right Hemisphere

Global processing

For most neurotypical individuals, language and spatial processing are broadly attributed to the left hemisphere (LH) and right hemisphere (RH) respectively (Pujol, Deus, Losilla, & Capdevila, 1999; Whitehouse & Bishop, 2009). An absence or reduced use of spoken language often pre-empts a subsequent diagnosis of ASC (Giacomo & Fombonne, 1998) and often persists across the individual's lifespan (Ballaban-Gil, Rapin, Tuchman, & Shinnar, 2016). Substantial research has been devoted to determining the neural underpinnings of impaired language in ASC, and one of the most prevailing findings has been the suggestion that language is atypically lateralized in these individuals (for a review, see Hollier, Maybery, & Whitehouse, 2014). However, given that visuospatial ability is more often viewed somewhat as a strength in ASC (Shah & Frith, 1983), it is surprising that relatively few studies have explored behavioural implications that this atypical lateralization might have for visuospatial processing in ASC individuals.

With respect to neurotypical individuals, it is possible that the drive for coherence and preference for globally-arranged stimuli stems from the fact that global processing is closely linked to the RH, which is generally more involved in visuospatial processing, whereas local processing is associated with the LH (for a review see Ivry and Robertson, 1998, see also: Evans, Shedden, Hevenor, & Hahn, 2000; Flevaris, Bentin, & Robertson, 2010; Hübner & Studer, 2009; Lux et al., 2004; Malinowski, Hübner, Keil, & Gruber, 2002; Volberg & Hübner, 2004; Weissman & Woldorff, 2005; Yamaguchi, Yamagata, & Kobayashi, 2000). As a result, global processing regions may be more readily activated than those associated with local processing, given that performance on tasks requiring attention to be focused on particular regions in space are relatively more dependent on intact RH functioning than on LH functioning (Heilman, 1995; Hellige, 1993). Evidence for this asymmetrical lateralization of visuospatial attention has primarily come from studies observing individuals with unilateral brain injuries to either the left or right hemisphere. While injuries or lesions to either hemisphere affect visuospatial ability, damage to the RH has by far the greatest impact, severely impacting performance on a range of tasks, including picture copying and line bisection (Gainotti, Messerli, & Tissot, 1972; Ivry & Robertson, 1998; Kaplan, 1983; Poizner, Klima, & Bellugi, 1990). It is thought that the RH controls the
distribution of attention to both the left and right visual fields while the LH controls attention only for the right visual field, and it is this absence of redundancies in the LH that potentially explains why visuospatial deficits are more common following RH damage than LH damage (Mesulam, 2000).

Following this notion, the reduced preference for global processing seen in ASC could be attributed to atypically reduced RH functioning for visuospatial processing in ASC. Supporting this view, many studies using behavioural and neurological measures have reported cortical abnormalities in ASC that are specific to the RH, including pragmatic language measures sensitive to right brain damage (Ozonoff & Miller, 1996; Siegal, Carrington, & Radel, 1996), functional and structural magnetic resonance imaging (Di Martino et al., 2011; Jou, Minshew, Keshavan, Vitale, & Hardan, 2010; A. T. Wang, Lee, Sigman, & Dapretto, 2007; Yamasaki et al., 2010) and electrophysiological measures (Keehn, Vogel-Farley, Tager-Flusberg, & Nelson, 2015; Lazarev, Pontes, & DeAzevedo, 2009; McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; Orekhova et al., 2009). Arguably, deficits or abnormalities in the RH in ASC may be manifest as a reduced preference for global processing.

Visual Neglect and Pseudoneglect

While indications of LH and RH activation levels may be obtained by observing local and global processing respectively, it is not the only method of detecting atypical hemispheric activation associated with visuospatial attention. If atypical hemispheric activation of visuospatial attention drives abnormal global and local processing biases in ASC, it should also yield atypical biases in other areas of visuospatial attention. For instance, individuals with lesions in one hemisphere commonly fail to detect visual stimuli presented in the contralateral visual field, a disorder known as hemispatial neglect (Heilman, 1995), and this is substantially more common following RH than LH damage (Costa, Vaughan, Horwitz, & Ritter, 1969; Gainotti et al., 1972). Patients with RH lesions resulting in left hemispatial neglect generally complete visuospatial tasks seemingly ignoring stimuli present in the left hemispace and consequently appearing to over-attend to items presented in the right hemispace. For example, on a line bisection task, which requires participants to mark the midpoint of a horizontal line, RH lesioned patients erroneously place the midpoint to the right of the actual centre (Bisiach, Bulgarelli, Sterzi, & Vallar, 1983; Harvey & Milner, 1999; Heilman, Watson, & Valenstein, 1997; Parton, Malhotra, & Husain, 2004; Poizner et al., 1990). On a cancellation task, which requires participants to place a cross over target items in an array, the same patients fail to cross out most targets presented in the left hemispace.
(Albert, 1973; Ferber & Karnath, 2001; Gauthier, Dehaut, & Joanette, 1989; Heilman et al., 1997). Finally, on a landmark task, which requires participants to indicate if a bisection on a horizontal line is closer to the left or right end of the line, patients with RH damage tend to bisect the line to the right of the true midpoint, as if perceiving the left half of the line to be shorter than it actually is or exaggerating how much space the right-side of the line takes up (Harvey & Milner, 1999; Heilman et al., 1997; Milner, Brechmann, & Pagliarini, 1992).

Critically, neurotypical individuals show an opposite attentional pattern. While RH lesioned patients make errors that are in line with a rightward shift of attention, neurotypical individuals generally err towards the left and, for example, bisect horizontal lines slightly leftward of the actual centre (for review, see Jewell & McCourt, 2000). This leftward bias in neurotypical individuals was termed pseudoneglect (Bowers & Heilman, 1980) due to the similarity it shares with hemispatial neglect, and may also be attributed to the overall greater involvement of the RH in visuospatial functioning (Fierro et al., 2000; Fink, Marshall, Weiss, Toni, & Zilles, 2002; Foxe, McCourt, & Javitt, 2003; Harris & Miniusi, 2003; Siman-Tov et al., 2007; Vingiano, 1991).

Direct evidence for a link between pseudoneglect and the RH lateralization of visuospatial attention stems from studies that manipulate hemispheric activation. One study used excitatory stimulation delivered via transcranial direct current (tDCS), a non-invasive technique that alters cortical excitability (for review, see Nitsche et al., 2008 and Utz, Dimova, Oppenländer, & Kerkhoff, 2010). Stimulation over the left posterior parietal cortex (PPC) eliminated pseudoneglect in neurotypical individuals, presumably by rebalancing activation asymmetries between the left and right PPCs (Loftus & Nicholls, 2012). Another research group had neurotypical participants complete a landmark task whilst receiving transcranial magnetic stimulation (TMS) to inhibit activation of the right PPC, finding that the TMS resulted in neglect-like rightward deviations on the task (Fierro et al., 2000; Fierro, Brighina, Piazza, Oliveri, & Bisiach, 2001). Finally, a study was recently conducted that used functional magnetic resonance imaging (fMRI) to confirm changes in hemispheric lateralization following TMS (Petitet, Noonan, Bridge, O’Reilly, & O’Shea, 2015). Neurotypical participants initially showed pseudoneglect on a computerized target detection task that required them to identify if visual targets were presented in the left, right, or both hemifields. After receiving TMS to the right angular gyrus/intra-parietal sulcus, pseudoneglect was
abolished, and fMRI confirmed that the relative balance of parietal activity had shifted from the RH to the LH.

With ASC, if the usual rightward hemispheric lateralization of attention is altered by a reduction in RH activation, it follows that we might expect to see a reduction in pseudoneglect, or even hemispatial neglect-like behaviours similar to those found in RH lesioned patients. The few studies that have investigated this notion have largely used face stimuli in their designs, as it is well documented that neurotypical individuals tend to explore the LVF of centrally presented face stimuli first, and for a longer duration, than the RVF (Butler et al., 2005; Everdell, Marsh, Yurick, Munhall, & Paré, 2007; Guo, Meints, Hall, Hall, & Mills, 2009; Guo, Smith, Powell, & Nicholls, 2012; Leonard & Scott-Samuel, 2005; Racca, Guo, Meints, & Mills, 2012; Smith, Gibilisco, Meisinger, & Hankey, 2013). The chimeric face task, which requires participants to decide which of two composite faces is a closer match for a given face prime, shows reduced LVF bias for adults with Asperger syndrome compared to controls (Ashwin, Wheelwright, & Baron-Cohen, 2005), and a later study using ASC children and emotional faces found an intact LVF bias for only two (happiness and anger) out of the six emotions presented (S. Taylor, Workman, & Yeomans, 2012). Eye-tracking studies have also reported a reduced LVF bias for human faces in ASC adults, ASC children, and infants with older ASC siblings, relative to controls (Dundas, Best, Minshew, & Strauss, 2012; Dundas, Gastgeb, & Strauss, 2012; Guillon et al., 2014). The pattern is also found in ASC children viewing stimuli of dog faces (Guillon et al., 2014), indicating that reduced LVF bias in ASC is not limited to the domain of human faces.

However, it is currently unknown if reduced LVF bias in ASC is specific to face stimuli or not, as studies using non-face stimuli are largely non-existent. While the only study, to my knowledge, that has investigated this issue did not find any attentional differences between a group of ASC and typically developing children (Rinehart, Bradshaw, Brereton, & Tonge, 2002), several factors may have contributed to this result that may have masked group differences. Critically, the typically developing group may be somewhat atypical in that they did not show any pseudoneglect, which conflicts with other reports (Dellatolas, Coutin, & De Agostini, 1996) and evidence suggesting that pseudoneglect decreases with age (Jewell & McCourt, 2000). Additionally, participants could not be screened for accuracy, and thus task engagement, and participants completed fewer than the recommended number of trials to ascertain a reliable bias (Nicholls, Bradshaw, & Mattingley, 1999).
It is possible that, when addressing these methodological issues, atypical visuospatial biases linked to autism may be also present for non-face stimuli. This could be considered potential evidence for the presence of atypical hemispheric lateralization in ASC that generalizes to visuospatial processing regions beyond those that are associated with face processing. Importantly, such findings may mark the presence of a previously unknown neurocognitive phenotype for ASC. Furthermore, it is also unknown if reduced LVF biases are present in individuals with high levels of autistic-like traits for any stimulus type. Considering that autism is thought to lie on a spectrum that extends into the neurotypical population, one may expect to find that the degree of pseudoneglect expression may decrease with increasing level of autistic-like traits. With this in mind, one aim of the present thesis is to test whether a relationship exists between pseudoneglect and autistic-like traits in large samples of neurotypical participants.

Representational Neglect and Pseudoneglect

Interestingly, RH damage appears to not just affect how visual space is perceived (as in the tasks just described), but also biases spatially-organized mental representations as well. One such representation is the mental number line. The mental number line can be described as a series of numbers located on a horizontal azimuth numerically ascending from left-to-right (Dehaene, Bossini, & Girau, 1993). When asked to determine the midpoint between any two numbers, RH damaged patients tend to select a number that is larger, or more 'rightward', than the actual midpoint, with greater rightward errors of judgement corresponding with neglect severity (Hoeckner et al., 2008; Zorzi, Prifti, & Umiltà, 2002). As with the line bisection task, this outcome suggests that RH damaged patients fail to appropriately consider the 'left' half of the stimulus, and appear to exaggerate the distance between numbers on the 'right' half of the mental number line. Similar patterns of behaviour by RH damaged patients have also been observed on other tasks. For alphabetical sequences, which are also thought to consist of a left-to-right mental organization (Gevers, Reynvoet, & Fias, 2003), RH damaged patients tend to perceive the alphabetical midpoint between two letters to be rightward of the actual midpoint (Zorzi, Prifti, Meneghello, Marenzi, & Umiltà, 2006). Furthermore, when tasked with recalling objects in a scene, RH damaged patients tend to describe more items that would be positioned in their imagined right visual field relative to the left visual field (Bisiach & Luzzatti, 1978; Guariglia, Padovani, Pantano, & Pizzamiglio, 1993).
Complementing findings in neurotypical participants regarding pseudoneglect for visual stimuli, healthy adults also show a small bias in mental number line representation in favour of selecting a lower, more 'leftward' number, relative to the true midpoint between any two numbers (Göbel, Calabria, Farnè, & Rossetti, 2006; Loftus, Nicholls, Mattingley, Chapman, & Bradshaw, 2009; Longo & Lourenco, 2007; Nicholls & McIlroy, 2010). Relatively greater activation of RH regions for visuospatial attention also likely underlies this representational form of pseudoneglect, resulting in the apparent exaggeration of the distance between numbers that are more “leftward” on the number line (similar to the exaggeration of leftward stimulus features of visual stimuli that results in pseudoneglect), shifting judgements as to the relative location of the central point (Loftus et al., 2009).

Taken together, the outcomes of these studies strongly imply that there is a common neural mechanism underlying physical and representational alterations of spatial bias. However, while several studies have found evidence for both physical and representational biases in the same patients (Aiello et al., 2012; Vuilleumier, Ortigue, & Brugger, 2004; Zorzi et al., 2006, 2002), others report that neglect patients who show rightward deviations on physical spatial tasks do not necessarily have similar biases in the representational medium (Aiello et al., 2012; Doricchi, Guariglia, Gasparini, & Tomaiuolo, 2005; Loetscher & Brugger, 2009; Loetscher, Nicholls, Towse, Bradshaw, & Brugger, 2010; Pia et al., 2012; Rossetti et al., 2011; Storer & Demeyere, 2014; van Dijck, Gevers, Lafosse, & Fias, 2012). These latter findings would suggest that, whilst aspects of the RH are potentially responsible for both forms of neglect, it is likely that at least partially disparate underlying networks are at play.

If disparate networks underlie physical and representational spatial biases for patients with RH damage, we potentially may observe dissociations regarding alterations of these spatial biases in individuals with ASC or neurotypical individuals with high levels of autistic-like traits. Therefore, it is important to consider representational as well as physical spatial biases in investigating atypical lateralization of spatial attention in ASC. Autism-related reductions in pseudoneglect on both physical and representational measures of spatial bias could be considered evidence for a common neural mechanism. However, finding reductions in only the physical measures of spatial bias would suggest that the mechanisms that underlie atypical lateralization of attention in autism are tied to processes within the visual perceptual system. Consequently, a second aim of the present thesis is to determine the
similarities or differences between pseudoneglect and representational pseudoneglect for individuals differing in levels of autistic-like traits.

Modulating attentional biases by increasing right hemisphere activation

Continuous performance task training

If reduced RH activation contributes to atypical attentional functioning in ASC, it is possible that increasing RH activation might serve to align performance on attentional tasks with that seen in neurotypical individuals. There is some evidence that engaging in a continuous performance task (CPT) activates RH regions and alters performance on visuospatial tasks for both neurotypical individuals and patients with RH damage (Degutis & Van Vleet, 2010; Van Vleet, Hoang-duc, DeGutis, & Robertson, 2011). The CPT is a computerized attentional training task during which participants must make speeded responses to the appearance of images of everyday objects on a computer monitor, whilst inhibiting responses to images of a pre-designated target category that comprises 10% of all trials. The task demands a high level of attention from the participant, which is driven by increases in tonic and phasic attention. Tonic attention, which refers to sustained attention over long periods of time, is linked to activation of the right inferior frontal, inferior parietal and anterior cingulate regions (Bartolomeo, 2014; Singh-Curry & Husain, 2009; Sturm & Willmes, 2001; Thiel, Zilles, & Fink, 2004), whilst phasic attention, which deals with moment-to-moment attention such as responding to the appearance of a stimulus, is linked to modulations of the right ventral fronto-parietal network and anterior cingulate region (Corbetta & Shulman, 2002).

In one study, RH lesioned patients completed landmark and visual search tasks before and after engaging in three 12-minute rounds of CPT training (Degutis & Van Vleet, 2010). It was reported that rightward biases for patients who completed the CPT training were temporarily eradicated on the tasks in the follow-up session, whereas patients who completed a control task that did not induce changes in tonic or phasic attention saw no changes in task performance. However, subsequent follow-up sessions showed that rightward biases in attention returned, indicating that the effects of CPT training were temporary. The absence of rightward attentional biases immediately following CPT suggests that the training task selectively activated regions in the RH associated with visuospatial attention. In a second study, neurotypical participants categorized global or local features of hierarchical figures (Navon, 1977)
in separate blocks in pre-CPT and post-CPT sessions (Van Vleet et al., 2011). Here, it was found that, compared to completing a control training task, engaging in CPT simultaneously reduced the interference produced by incongruent local features when categorizing the global feature, and increased the interference produced by incongruent global features when categorizing the local feature. Like the first study, it was suggested that these modulations of attention were brought about due to relatively greater activation of RH regions associated with global processing following a brief engagement with CPT.

Critically, leftward shifts in attention (Degutis & Van Vleet, 2010) and increased preference for globally-organized visual stimuli (Van Vleet et al., 2011) can both be interpreted as behavioural evidence for relatively increased RH activation during the short period following training. If attentional preferences in ASC are driven by relatively reduced RH activation for visuospatial attention, then CPT may be an effective tool for temporarily increasing RH activation and potentially ‘normalizing’ visuospatial attention for individuals with ASC and neurotypical individuals with high levels of autistic-like traits. The third aim of the present thesis tests this notion, and explores whether different levels of autistic-like traits impact the effectiveness of CPT. It could be presumed that if, for any given reason, high trait neurotypical individuals resist CPT training and attention remains unaltered, that the same results would likely be seen in a clinical ASC sample. Therefore, this experiment will provide a preliminary indication as to whether CPT in the broader context of ASC is a worthwhile pursuit.

**Transcranial direct current stimulation**

As mentioned earlier, the degree of lateralization of hemispheric activation can be modulated via non-invasive techniques that temporarily alter cortical excitability, with several studies showing that alterations of PPC excitability affect visuospatial attentional biases. In each of these studies, increasing right PPC activation via anodal tDCS induced a leftward shift in attention in both neurotypical individuals and RH-damaged patients (Roy, Sparing, Fink, & Hesse, 2015; Sparing et al., 2009), whilst disrupting right PPC activation (using cathodal tDCS or TMS) was generally associated with a rightward shift in attention (Fierro et al., 2000, 2001; Petit et al., 2015; Sparing et al., 2009). On the other hand, stimulation of the left PPC produces the converse pattern of effects (e.g. increased activation invokes rightward shifts of attention; Loftus & Nicholls, 2012; Sparing et al., 2009). Furthermore, TMS over the right PPC also causes a rightward shift on a number line bisection task (Göbel et al., 2006), suggesting
that the PPC is important to the allocation of spatial attention for both physical and mentalized stimuli.

If reduced RH activation underlies variation in visuospatial attention in individuals with ASC, it follows that increasing RH activation using techniques such as tDCS may reduce or ameliorate these deficits. Previously in this introduction, it was predicted that neurotypical individuals with high levels of autistic-like traits would show reduced levels of pseudoneglect relative to individuals with low levels of autistic-like traits – a consequence of relatively reduced RH activation in the high trait group. Assuming that prediction is correct, could tDCS over the right PPC be used to increase pseudoneglect in the high trait group? The fourth aim of the present thesis is to examine this question by determining how anodal and cathodal tDCS alter visuospatial biases on a visuospatial lateralization task for neurotypical individuals with high and low levels of autistic-like traits. As prior work has demonstrated that anodal tDCS can be effective at increasing pseudoneglect for a neurotypical sample (Roy et al., 2015; Sparing et al., 2009), it stands to reason that the stimulation technique should be particularly effective for a high autistic trait sample who potentially have RH baseline activation levels that are lower relative to low trait individuals. Furthermore, the potential presence of low trait individuals with higher pseudoneglect baselines may account for the absence of right PPC stimulation effects in one study (Loftus & Nicholls, 2012).

**Summary**

Social difficulties are a defining trait in ASC and it is likely that these difficulties can be at least partly attributed to atypical attentional processes. Investigation into atypical global/local biases has dominated this field thus far, but decades of research has not led to firm conclusions. That said, the most recent meta-analysis of the literature suggests that global processing is slowed in ASC relative to neurotypical individuals (Van der Hallen et al., 2015). It is possible that atypical activation of the RH is responsible for slowed global processing in ASC given that the RH typically has a substantial role in global processing, and that several neurological studies have found evidence for cortical abnormalities in this hemisphere linked to ASC. However, if broad deficits in the RH are responsible for reduced global processing ability in ASC, it is likely that other attentional abnormalities exist too. There is some evidence to suggest that individuals with ASC show a reduced LVF bias when viewing faces that is not dissimilar to RH lesioned patients. However, no research has yet explored whether this
atypical lateralization of attention in ASC extends to visual stimuli in general, or is specific to faces.

**Thesis overview**

To broadly summarize the present thesis, I examine several aspects of attention in individuals with high levels of autistic-like traits. To achieve this, I employ established tasks, including the greyscales, landmark and mental number line tasks, which have not previously been used in to explore how the distribution of attention alters as a function of levels of autistic-like traits. Using these tasks, I provide novel evidence of reduced RH activation during visual attentional tasks for individuals with high levels of autistic-like traits compared to their low autistic trait counterparts. Furthermore, I test whether pre-existing attentional differences in low and high autistic-trait individuals can be reduced or eliminated using two different techniques that are understood to increase RH activation – CPT training and anodal tDCS. As noted earlier, observing the performance of neurotypical individuals differing in autistic-like traits can be a useful method of conducting research in the field of autism, as generally these individuals can be recruited in much larger numbers than individuals with clinical ASC, and studies that use low-trait/high-trait comparisons often report findings comparable to those gathered from neurotypical/ASC comparisons (Landry & Chouinard, 2016). Thus, while the findings reported in this thesis for comparisons between low and high autistic trait individuals are not conclusive of what might be presented in a neurotypical/ASC comparison, the results can be considered highly indicative of what might be found in such clinical studies, and certainly encourage further investigation using clinical groups.

The present thesis has two distinct halves. In the first half (Chapters Two and Three), I report two experiments that provide novel evidence for RH abnormalities in individuals with high levels of autistic-like traits. In the second half (Chapters Four and Five), I detail using two different techniques to selectively engage attentional mechanisms in the RH and modify differences in biases in visuospatial attention between individuals with low and high levels of autistic-like traits. In short, the thesis provides novel evidence for reduced RH activation during attentional tasks for individuals with relatively high levels of autistic-like traits, and examines methods that may reduce 'atypical' hemispheric lateralization for these same individuals. The broad aims and outcomes of each chapter are outlined below.
In the second chapter, a study is reported that shows a difference in attentional bias on the greyscales task (Nicholls et al., 1999) for participants with low and high levels of autistic-like traits. The greyscales task is similar to other previously described lateralization tasks in that visuospatial biases are reflected in over-exaggeration of the left or right side of a visual stimulus. In this task, participants are presented with two horizontal bars that are evenly shaded, from the left, black-to-white for one, and white-to-black for the other. While participants are tasked with selecting the bar they believe is darker (i.e. has more black shading), a preference for selecting the bar that has the black shading on the left side is indicative of pseudoneglect (i.e. exaggeration of shading in the left visual field). The results of this study represent the first evidence that pseudoneglect is reduced in individuals with high levels of autistic-like traits relative to those with low trait levels, and as such, provide behavioural evidence of reduced RH activation in high trait individuals for visuospatial attention.

This initial finding is followed up in the third chapter, which extends the results to an alternative measure of physical spatial bias (landmark task) as well as examining biases in representational space using the mental number line task. By using these additional tasks, it could be determined whether the finding presented in Chapter Two is specific to the greyscales task, and whether representational space, which does not depend on the visual perceptual system, is also subject to reduced spatial bias in individuals with high levels of autistic-like traits, consistent with a single underlying mechanism for reduced physical and representational pseudoneglect. In line with the findings in Chapter Two, high autistic trait participants showed a reduced bias on both the greyscales and landmark tasks relative to low trait individuals, which provides further evidence for reduced RH activation by high trait individuals for visuospatial attention. In contrast, no group difference was found for the representational, mental number line task, suggesting that the mechanism responsible for reduced leftward bias in high trait individuals is tied to the visual perceptual system.

The fourth chapter moves from observation of attentional behaviours that are consistent with RH impairments for individuals with high levels of autistic-like traits to evaluating methods of modulating attention to reduce the differences between individuals with low or high levels of autistic-like traits. Here, the continuous performance task (CPT) described earlier is used as a training task. Recall that the CPT is purported to activate regions in the RH associated with increases in global preference in hierarchical Navon figures for neurotypical individuals (Van Vleet et al., 2011) and with the reduction of left hemispatial neglect for individuals with RH
damage (Degutis & Van Vleet, 2010). In the study reported in Chapter Four, a short period of CPT successfully increased the amount of attention individuals with high levels of autistic-like traits directed to the global level of a hierarchical figure when participants were instructed to observe the local aspects, but did not lead to a complementary reduction in the degree of attention directed to local stimuli when participants were instructed to attend to the global level. In summary, individuals with high levels of autistic-like traits showed greater attendance to global arrangements of stimuli following the CPT, which is a desirable result that encourages further exploring the effectiveness of CPT in modifying patterns of attention to social stimuli that contain global arrangements, such as faces.

In the fifth chapter, a second technique, tDCS, was used to influence RH activation and the resulting distribution of visuospatial attention in individuals with high and low levels of autistic-like traits on the greyscales task. It was predicted that anodal tDCS would elicit the greatest increase in pseudoneglect for the High AQ group, given their relatively lower baseline levels of LVF bias that were found in Chapters Two and Three. Furthermore, it was expected that cathodal tDCS would show the greatest reductions in pseudoneglect for the Low AQ group, given their relatively higher baselines. While anodal tDCS did increase pseudoneglect for the High AQ group as predicted, no increase was found for the Low AQ group, and cathodal tDCS failed to reduce pseudoneglect for either group. However, considering that the primary focus of the study was to increase pseudoneglect through stimulation of the right PPC for the High AQ group, these results are particularly encouraging, and warrant further investigation with a clinical autistic sample.

The final, sixth chapter consists of the General Discussion, which summarizes the findings of this thesis and integrates them into the current literature. I examine how the findings presented in Chapter Two and Three provide novel evidence of reduced RH activation for visuospatial attention in individuals with high levels of autistic-like traits, and speculate on what regions and pathways specific to the visual perceptual system might be implicated, given that normal biases were found for a non-perceptual, mental representation of space. Furthermore, I explore how the modulations of attention examined in Chapters Four and Five may be used in the context of intervention to potentially improve attentional outcomes for people with ASC.
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CHAPTER TWO

Individuals with autistic-like traits show reduced lateralization on a greyscales task

Michael C.W. English, Murray T. Maybery and Troy A.W. Visser

Individuals with autism spectrum conditions attend less to the left side of centrally presented face stimuli compared to neurotypical individuals, suggesting a reduction in right hemisphere activation. To determine if this difference extends to non-facial stimuli, we measured spatial attention bias using the “greyscales” task in a large sample of neurotypical adults rated above- or below-average on the Autism Spectrum Quotient. The typical leftward bias in the below-average group was significantly reduced in the above-average group. Furthermore, a negative correlation between leftward bias and the Social Skills factor of the Autism Spectrum Quotient provides additional evidence for a link between atypical hemispheric activation and social difficulties in autism spectrum conditions that extends to non-facial stimuli and the broader autistic phenotype.

Individuals with autism spectrum conditions (ASC) display many atypical behaviours ranging from impaired social interactions to superior visuospatial skills (Shah & Frith, 1983; Soulières, Zeffiro, Girard, & Mottron, 2011). Evidence from pragmatic language
measures (Ozonoff & Miller, 1996; Siegal, Carrington, & Radel, 1996), functional and structural magnetic resonance imaging (Di Martino et al., 2011; Jou, Minshew, Keshavan, Vitale, & Hardan, 2010) and electrophysiological recordings (Lazarev, Pontes, & DeAzevedo, 2009; Orekhova et al., 2009) suggests that right hemisphere (RH) abnormalities may contribute to the development of these behaviours. Here, we investigate whether high levels of autistic-like traits are also linked to RH-based atypical biases in spatial attention.

There is substantial evidence that spatial attention is RH lateralized (Davidson & Hugdahl, 1996; Hellige, 1993). Stroke patients with RH parietal lesions preferentially focus on stimuli in the right visual field and ignore those in the left (Adair & Barrett, 2008; Bartolomeo, 2007), while neurotypical participants display the opposite pattern. Neurotypical individuals bisect lines to the left of veridical centre (pseudoneglect; Bowers & Heilman, 1980) and on the “greyscales” task (Mattingley, Bradshaw, Nettleton, & Bradshaw, 1994), in which observers must choose the “darker” of two symmetrical, equiluminant bars (see Figure 2.1), they preferentially choose the bar that is darker on the left (Dellatolas, Coutin, & De Agostini, 1996; Jewell & McCourt, 2001). Both of these tasks elicit a reliable left visual field (LVF) bias and are suggestive of relatively greater involvement of the RH in spatial attention (Nicholls, Bradshaw, & Mattingley, 1999).

With respect to autism, findings on lateralization of attention are mixed. Adults with ASC show reduced fixation-time to the LVF when viewing centrally-presented faces (Dundas, Best, Minshew, & Strauss, 2012) and reduced LVF bias for identification of chimeric faces (Ashwin, Wheelwright, & Baron-Cohen, 2005) compared to neurotypical adults. However, on a numerosity-judgement task with non-facial stimuli, adults with ASC show a LVF bias while neurotypical adults do not (Ashwin et al., 2005). Finally, in children, Rinehart, Bradshaw, Brereton and Tonge (2002) reported that neither a neurotypical group nor a group of children with ASC showed LVF biases1. The significant disparities across these studies could reflect a unique role for face-specific mechanisms or differences between adults and children. Alternatively, inconsistencies might also stem from relatively small samples or insufficient trial numbers to obtain reliable measures of spatial biases (Nicholls et al., 1999). Finally, task engagement could not be monitored in Ashwin et al. (2005) and Rinehart et al. (2002) because

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1 Rinehart et al. (2002) used non-face, greyscales stimuli, highly similar to those used in the present study.
stimuli in the greyscales task were actually equiluminant, making it impossible to measure performance accuracy.

To address these issues, we modified the greyscales task (Nicholls et al., 1999) by increasing the number of trials and introducing a luminance difference between the bars on each trial. This allowed us to screen for task engagement, as well as estimate spatial attention bias. We also tested a large sample of adults classified as having low versus high levels of autistic-like traits using the Autism Spectrum Quotient questionnaire (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Past research suggests there is a broader autism phenotype that extends into the ‘normal’ population (Baron-Cohen & Hammer, 1997; Baron-Cohen et al., 2001; Bishop et al., 2004), with non-clinical individuals exhibiting high levels of autistic-like traits, as measured by the AQ, showing similar behavioural patterns to ASC-diagnosed individuals (Bayliss & Kritikos, 2011; Grinter, Van Beek, Maybery, & Badcock, 2009; Grinter, Maybery, et al., 2009; Rhodes, Jeffery, Taylor, & Ewing, 2013; Russell-Smith, Maybery, Bayliss, & Sng, 2012; Sutherland & Crewther, 2010). It should be noted that some researchers have raised potential issues with the use of AQ-selected groups as proxies for ASC (Gregory & Plaisted-Grant, 2013), arguing that differences between low- and high-trait groups might be driven by undiagnosed individuals with an ASC phenotype who are included in the high-trait group. We addressed this issue in two ways; first, by testing a particularly large sample of participants and, second, by comparing the entire distribution rather than just the extreme ends. Thus, while undiagnosed individuals with ASC may form part of the high-trait group, they are unlikely to be the sole source of group differences.

**Methods**

**Participants**

Participants were 332 right-handed psychology students (93 male; mean age 21.27) at the University of Western Australia.

**Materials and Procedure**

**Questionnaires**

The AQ (Baron-Cohen et al., 2001) is a 50-item self-report questionnaire assessing autistic-like traits and behaviours in neurotypical individuals (items scored 1-4 using Austin's (2005) method; higher scores indicate more autistic-like traits). We
calculated scores for overall AQ and three subfactors: Social Skills, Details/Patterns, and Communication/Mind Reading (Hurst, Mitchell, Kimbrel, Kwapił, & Nelson-Gray, 2007; Russell-Smith, Maybery, & Bayliss, 2011). Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971).

**Greyscales Task**

Stimuli were presented using custom software², following the procedure of Nicholls et al. (1999). Participants were seated approximately 50cm from a monitor (HP L2245wg) and instructed to keep their eyes fixated on the display's centre. Two horizontal bars were presented above and below the display centre on each trial (Figure 2.1) for 5000ms with one bar slightly darker than the other (200px difference). Participants identified the darker bar by pressing the 'T' or 'B' key to indicate the top or bottom bar respectively. A trial terminated when a response was made. This meant that a response could still be recorded when the bars had been removed, although participants were encouraged to respond while the bars were present. The next trials began 1500ms after the previous response. Participants completed 96 trials, with the darker bar appearing equally often on the top or bottom and shaded darker to the left or right.

![Figure 2.1. Example of a stimulus presented in the greyscales task.](image)

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² Stimuli were generated, presented and participant responses recorded using custom software developed by Young Ho Kim, Mike Nicholls and Jason Mattingley downloaded from Mike Nicholls' website accessible here: [http://flinders.edu.au/sabs/psychology/research/labs/brain-and-cognition-laboratory/the-greyscales-task.cfm](http://flinders.edu.au/sabs/psychology/research/labs/brain-and-cognition-laboratory/the-greyscales-task.cfm).
Results

Task accuracy was calculated as the percentage of correct identifications of the darker bar on trials with response times from 200-5000ms. Participants with ≤50% accuracy (n=43) or with more than 1/3 of trials with response times ≤200ms or ≥5000ms (n=16) were excluded from the analysis (four participants met both exclusion criteria). The remaining 277 participants were divided into Low and High AQ groups based on a median split of AQ scores (Median=105; see Table 2.1 for descriptive statistics).

Table 2.1. Characteristics of AQ comparison groups.

<table>
<thead>
<tr>
<th></th>
<th>Low AQ</th>
<th>High AQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>135 (26 male)</td>
<td>142 (44 male)</td>
</tr>
<tr>
<td>AQ</td>
<td>94.90</td>
<td>115.14</td>
</tr>
<tr>
<td>Age (years)</td>
<td>22.56</td>
<td>20.33</td>
</tr>
<tr>
<td>Median</td>
<td>97</td>
<td>113</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>7.84</td>
<td>8.56</td>
</tr>
<tr>
<td>Range</td>
<td>36 (68-104)</td>
<td>44 (105-149)</td>
</tr>
</tbody>
</table>

* The 12 oldest participants in the study were all classified as Low AQ, explaining the larger range and standard deviation for this group relative to the High AQ group. As subsequent analyses showed the same pattern of results regardless of the inclusion or exclusion of these participants, they were not removed from the dataset.

As summarized in Figure 2.2, mean accuracy for both groups was significantly better than chance (both groups: \( p < .001 \), both \( d' > 2.54 \)), and did not differ between groups (\( p = .92 \), \( d = .01 \)). Spatial bias was measured as the percentage of responses indicating the bar shaded to the left was darker, irrespective of actual luminance. Both groups made significantly more leftward responses than expected by chance (Low AQ: \( p < .001 \), \( d = 1.21 \); High AQ: \( p = .005 \), \( d = .48 \)), indicating a leftward spatial attention bias. A between-groups analysis of variance was conducted to determine if there was a difference in spatial bias between AQ groups. As the High AQ showed a significantly

\[^3\]These exclusion criteria were used in order to exclude participants that were clearly not appropriately engaging with the task and the usable portion of their data could not be relied upon to be a true indicator of their attentional biases. For those interested, removing the accuracy criterion results in weaker, but still significant difference between the AQ groups (\( p = 0.03 \)), and increasing the minimum accuracy to 60% also results in a slightly weaker, but still significant, difference between the AQ groups (\( p = 0.01 \)).
greater proportion of male participants compared to the Low AQ group following a chi-square test, χ²(1)=5.04, p=.03, participant sex was entered as a between-groups factor in addition to AQ group in a 2x2 mixed-design analysis of variance. This analysis yielded a main effect of AQ group, F(3,273)=5.28, p=.02, η²p = .02, with the Low AQ group reporting a significantly greater proportion of leftward responses compared to the High AQ group (see Figure 2.2). However, neither the main effect of sex nor the interaction was significant (all p’s>.18, all η²p<.01).

Table 2.2 summarizes correlations between spatial bias and scores for the AQ and its subfactors. As sex was not reported to significantly influence bias in the prior analysis, data for the two sexes were combined for the correlational analysis. As can be seen in Table 2.2, the negative correlation between spatial bias and overall AQ approached significance, while the negative correlation of spatial bias with the Social Skills subfactor was significant (illustrated in Figure 2.3).

Figure 2.2. Proportion of trials in which participants correctly selected the darker bar, and the bar with the black end oriented towards the left-side of the screen. Error bars represent SEM.

Table 2.2 summarizes correlations between spatial bias and scores for the AQ and its subfactors. As sex was not reported to significantly influence bias in the prior analysis, data for the two sexes were combined for the correlational analysis. As can be seen in Table 2.2, the negative correlation between spatial bias and overall AQ approached significance, while the negative correlation of spatial bias with the Social Skills subfactor was significant (illustrated in Figure 2.3).^4

^4It should be acknowledged that the correlation between Social Skills and Spatial Bias, though statistically significant, is relatively weak and may represent a Type I error. However, it is
Table 2.2. Correlation of spatial bias with AQ total and subfactor scores. Numbers in parentheses indicate significance levels.

<table>
<thead>
<tr>
<th>Spatial Bias / Left Responses</th>
<th>Overall AQ</th>
<th>Social Skills</th>
<th>Details / Patterns</th>
<th>Communication / Mindreading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-.09</td>
<td>-.12*</td>
<td>-.01</td>
<td>-.04</td>
</tr>
<tr>
<td></td>
<td>(.12)</td>
<td>(.046)</td>
<td>(.90)</td>
<td>(.56)</td>
</tr>
</tbody>
</table>

Figure 2.3. Scatterplot illustrating the distribution of spatial bias scores against the AQ: social skills subfactor.

Finally, to address concerns raised by Gregory and Plaisted-Grant (2013), we re-conducted all analyses whilst excluding participants whose AQ was above the 95th percentile (AQ>127, 12 participants). This was designed to omit participants most critical to note that it is in the expected direction, and is supported by previous work indicating that attentional differences between Low and High AQ groups is linked to this subfactor, and not the others (Russell-Smith et al. 2012), and thus we believe this is not a chance effect.
likely to be those with undiagnosed ASC. The resulting analyses yielded the identical pattern of results.

**Discussion**

The present results reveal a robust LVF bias of spatial attention that is significantly reduced in High- compared to Low AQ observers. This echoes previous results using facial stimuli (Ashwin et al., 2005; Dundas et al., 2012), and provides additional evidence that ASC is linked to RH abnormalities. These findings also extend this previous work by showing a reduced LVF bias with non-facial stimuli for individuals with high levels of autistic traits. In contrast to Ashwin et al. (2005) and Rinehart et al. (2002) who did not find a LVF bias in their control groups, we demonstrate the typical LVF bias in our Low AQ group in conjunction with reduced LVF bias for the High AQ group. In the case of Rinehart et al. (2002), this discrepancy is unlikely to reflect effects of maturation, as previous studies have found robust LVF biases in children (Dellatolas et al., 1996) and a decline in bias with age (Jewell & McCourt, 2000). Instead, we suggest that differences stem from our larger sample, additional trials, and screening to ensure task engagement.

Our correlation analysis revealed a somewhat surprising association between LVF bias and the Social Skills subfactor of the AQ, where greater levels of social difficulty were associated with reduced LVF bias. A similar pattern of results has been previously reported by Russell-Smith et al. (2012), who found that high scores on the Social Skills subfactor (greater social difficulty) were associated with superior performance on the Embedded Figures Test (EFT; Witkin, 1971) in which participants must locate a simple geometric shape within a relatively complex scene. Like the greyscales task, High- and Low AQ groups perform differently on the EFT, with High AQ participants typically outperforming Low AQ participants (Almeida, Dickinson, Maybery, Badcock, & Badcock, 2010a, 2010b, 2013; Grinter, Van Beek, et al., 2009; Grinter, Maybery, et al., 2009). The performance difference between groups is thought to stem from High AQ individuals difficulties with global integration (Grinter, Maybery, et al., 2009), a processing style that interferes with the task objective in the EFT by drawing attention away from the details of a scene and instead towards the holistic picture. Importantly, global processing is closely associated with activation of RH regions (Fink et al., 1996; Heinze, Hinrichs, Scholz, Burchert, & Mangun, 1998; Hübner

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5 Results of the independent samples t-test between AQ groups on spatial bias: \( t(263) = 3.00, p < 0.01, d = 0.37 \). Results of the correlation analysis between spatial bias and: AQ, \( r = -0.12, p = 0.05 \); AQ: Social Skills, \( r = -0.15, p = 0.02 \); other subfactors, n.s.
& Studer, 2009; Martinez et al., 1997) and thus High AQ individuals’ superior performance on the EFT can be interpreted as further evidence of relatively reduced activation in the RH.

Interestingly, both our study and Russell-Smith et al. (2012) found associations between task performance and the Social Skills subfactor of the AQ, but not the arguably more visuo-spatially oriented Details/Pattems subfactor. Furthermore, similar patterns of behaviour have been reported between other social constructs and visuo-spatial performance (Baron-Cohen & Hammer, 1997; Jarrold, Butler, Cottington, & Jimenez, 2000; Pellicano, Maybery, Durkin, & Maley, 2006). However, the underlying cause of this relationship remains unclear. One potential explanation is that face processing, a skill that is particularly important in regard to processing non-verbal, social information (Speer, Cook, McMahon, & Clark, 2007), is associated with increased activation in RH regions, especially in the right fusiform gyrus (Clark et al., 1996; Haxby et al., 1994, 1999; Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997; Rossion, Schiltz, & Crommelinck, 2003; Sergent, Ohta, & Macdonald, 1992). If LVF bias, as measured by the greyscales task, is related to levels of relative RH activity for spatial attention, then it is possible that a relative reduction in LVF bias may also be associated with a reduction in activation of face processing regions and, by extension, potentially-elevated levels of social difficulty. Of course, this explanation is necessarily speculative and awaits further empirical testing.

On a final note, it is important to consider what brain regions might account for the reduced LVF bias in High AQ observers. Loftus and Nicholls (2012) hypothesized that pseudoneglect in neurotypical samples is due to asymmetrical activation of the left-and-right posterior parietal cortices (PPC), with the right PPC more active than left PPC. Consistent with this, they abolished pseudoneglect in neurotypical individuals by administering anodal (excitatory) transcranial direct current to the left PPC. On this account, we can conjecture that reduced leftward spatial bias in our High AQ group reflects more balanced reliance on left and right PPCs. Further research will be required to test this possibility and whether it reflects greater activation in left PPC or reduced activation in right PPC. Finally, it is also critical to replicate the present findings in samples with ASC in order to ensure the broad applicability of our results.
INDIVIDUALS WITH HIGH AQ SHOW REDUCED LATERALIZATION ON A GREYSCALES TASK

References


Reduced pseudoneglect for physical space, but not mental representations of space, for adults with autistic traits

Michael C.W. English, Murray T. Maybery, Troy A.W. Visser

Neurotypical individuals display a leftward attentional bias, called pseudoneglect, for physical space (e.g. landmark task) and mental representations of space (e.g. mental number line bisection). However, pseudoneglect is reduced in autistic individuals viewing faces, and neurotypical individuals with autistic traits viewing ‘greyscale’ stimuli, suggesting attention is atypically lateralized in autism. We investigated whether representational pseudoneglect for individuals with autistic traits is also reduced by comparing biases on greyscales, landmark, and mental number line tasks. We found that pseudoneglect was intact only on the representational measure (i.e. the mental number line task), suggesting that mechanisms for atypical lateralization of attention in individuals with autistic traits are specific to processing of physical, visual stimuli.

Asymmetries in brain hemispheric activation have been shown to have contralateral effects on visual attention. Stroke patients with right hemisphere (RH) lesions, for example, focus on stimuli presented primarily in the right visual field (RVF) and ignore
(neglect) stimuli presented in the left (Adair & Barrett, 2008; Bartolomeo, 2007; Heilman, Watson, & Valenstein, 2003). When completing line bisection tasks (which require indicating the centre of a line) or landmark tasks (which require indicating whether a pre-bisected line has been divided to the left or right of centre), these patients reliably respond as if the centre of the line was towards the right of the true centre.

Interesting, while neglect of the left visual field (LVF) is a common outcome following RH damage, neglect of the RVF following left hemisphere (LH) damage, is relatively less common (Stone, Halligan, & Greenwood, 1993). Increased connectivity within the RH, as well as inter-hemispheric connectivity that favours information transfer in a right-to-left direction (Siman-Tov et al., 2007), are factors that underlie the widely accepted theory that the RH controls spatial attention for both LVF and RVF, while the LH controls spatial attention only for the RVF (Mesulam, 1981) explaining why neglect of the RVF following LH damage is relatively rare, whereas neglect of the LVF following RH damage is common.

The relatively greater lateralization of spatial attention to the RH (Heilman, 1995; Hellige, 1993) can also be used to account for the fact that healthy individuals show a leftward attentional bias (pseudoneglect; Bowers & Heilman, 1980). A side effect of the RH lateralization for spatial attention is that stimulus properties in the ‘dominant’ LVF are exaggerated relative to stimulus properties presented in the other visual field. As a result, neurotypical individuals bisect lines slightly left of the line’s true centre (Jewell & McCourt, 2000) and show leftward attentional biases when making stimulus judgements on the basis of brightness and numerosity (Nicholls, Bradshaw, & Mattingley, 1999).

Atypical lateralization of spatial attention is not unique to neglect patients with RH lesions. It has also been linked to autism spectrum conditions (ASC), neurodevelopmental conditions primarily characterized by deficits in social communication and restricted and repetitive behavioural patterns (American Psychiatric Association, 2013). Relative to neurotypical participants, ASC adults usually show a reduced LVF bias in target detection tasks (Wainwright & Bryson, 1996) and chimeric face identification (Ashwin, Wheelwright, & Baron-Cohen, 2005), as well as reduced fixation time to the left side of centrally presented faces (Dundas, Best, Minshew, & Strauss, 2012). Recently, we also reported that neurotypical individuals with relatively high scores on the Autism Spectrum Quotient (AQ; a measure of autistic-like traits in neurotypical participants; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley,
2001) show reduced pseudoneglect on the greyscales task (see a description and example stimuli below) compared to participants with lower AQ scores (Chapter Two of the present thesis, henceforth: English, Maybery, & Visser, 2015). This was the first study to suggest that attenuations of attentional bias found in ASC are also present in a high autistic-trait subset of the neurotypical population and adds to the growing literature indicating that attentional characteristics associated with ASC also manifest to a lesser degree in individuals with higher scores on measures of autistic-like traits (Bayliss & Kritikos, 2011; Grinter, Van Beek, Maybery, & Badcock, 2009; Grinter, Maybery, et al., 2009; Rhodes, Jeffery, Taylor, & Ewing, 2013; Russell-Smith, Maybery, Bayliss, & Sng, 2012; Sutherland & Crewther, 2010; for a meta-analysis, see Cribb, Olaíthe, Di Lorenzo, Dunlop, & Maybery, 2016).

The present work examines whether spatially-organized mental representations, like the mental number line, are also altered in individuals with high levels of autistic-like traits. Figure 3.1 is a conceptual illustration of such a number line, which is described as a series of numbers located on a horizontal azimuth numerically ascending left-to-right (Brooks, Sala, & Darling, 2014). Past research has shown that when patients with neglect are asked to make a judgement regarding numerical distance, their responses are indicative of a rightward bias on the number line (e.g. selecting ‘7’ as the midpoint between ‘1-9’), with the size of the bias corresponding with neglect severity (Hoeckner et al., 2008; Loftus, Nicholls, Mattingley, Chapman, & Bradshaw, 2009; Zorzi, Priftis, & Umiltà, 2002). Conversely, neurotypical participants show a small bias in favour of a lower, more 'leftward' number (Göbel, Calabria, Farnè, & Rossetti, 2006; Loftus et al., 2009; Longo & Lourenco, 2007; Nicholls & McIlroy, 2010). This representation pseudoneglect is hypothesised to occur due to exaggeration of the distance between numbers that are more "leftward" on the number line (similar to the exaggeration of leftward stimulus features of visual stimuli that results in pseudoneglect), shifting perceptions for the relative location of the central point (Loftus et al., 2009).
Figure 3.1. A simplified demonstration of how leftward representational bias occurs in the mental number line. It is suggested that individuals exaggerate the distance between numbers that are further “left” on the mental number line. Thus, when an individual is asked to identify the midpoint of the range 0-10, ‘four’ is erroneously reported more often than the correct answer of ‘five’.

While both visual and representational stimuli yield leftward biases in neurotypical participants, it is unclear whether both types of bias would also disappear for individuals high in autistic traits. This is partly because evidence from past studies is equivocal with respect to the question of whether these two types of leftward bias have a common neural substrate. One candidate region for such a substrate is the posterior parietal cortex (PPC) due to its involvement in many aspects of visual attention, including visual working memory (Berryhill & Olson, 2008), sustained attention (Husain & Nachev, 2007; Malhotra, Coulthard, & Husain, 2009), visually guided reaching (Clower et al., 1996), initiating visually guided saccades (Luna et al., 1998), and activating mentalised spatial maps (Maguire et al., 1998). Non-invasive stimulation of this region has been effective at modulating spatial biases. For example, applying transcranial magnetic stimulation (TMS) to the right PPC of healthy individuals temporarily disrupts its activation (Fierro, Brighina, Piazza, Oliveri, & Bisiach, 2001), producing a rightward shift in the perceived midpoint of horizontal lines similar to that shown by individuals with RH damage (Bjoertomt, Cowey, & Walsh, 2002). Likewise, applying TMS over the same region in healthy individuals produces a rightward shift for representational space in the mental number line task, similar to those observed in individuals with right parietal damage (Göbel et al., 2006).

Additionally, Loftus and Nicholls (2012) found that pseudoneglect, measured with the luminance-judgement greyscales task (Nicholls et al., 1999), could be eliminated following anodal transcranial direct current stimulation (tDCS) over the left parietal cortex. Anodal tDCS is thought to increase neural excitation of the stimulated site and, in line with Siman-Tov et al.’s (2007) activation-orientation model of attention, likely caused a relative increase in the excitation of neurons in the left parietal cortex which
rebalanced the asymmetry in activation between the left and right hemispheres that drives pseudoneglect.

While such studies provide evidence in favour of the notion that PPC activity underlies both physical and representational pseudoneglect, and while several studies have found evidence for both physical and representational biases in the same individuals (Aiello et al., 2012; Longo, Trippier, Vagnoni, & Lourenco, 2015; Rotondaro, Merola, Aiello, Pinto, & Doricchi, 2015; Vuilleumier, Ortigue, & Brugger, 2004; Zorzi, Priftis, Meneghello, Marenzi, & Umiltà, 2006; Zorzi et al., 2002), other researchers have found that neglect patients who show rightward deviations on physical spatial tasks do not necessarily have similar biases in the representational medium, suggesting that at least partially disparate underlying networks are at play (Aiello et al., 2012; Doricchi, Guariglia, Gasparini, & Tomaiuolo, 2005; Loetscher & Brugger, 2009; Loetscher, Nicholls, Towse, Bradshaw, & Brugger, 2010; Pia et al., 2012; Rossetti et al., 2011; Storer & Demeyere, 2014; van Dijck, Gevers, Lafosse, & Fias, 2012). Moreover, there are many fundamental differences between physical and representational stimuli that might result in the recruitment of different neural mechanisms during processing. For one, physical representations, like those in the line bisection and greyscale tasks, act as visual cues that directly influence attentional processes, whereas few or no such cues are present in the representational mental number line. Second, the differences could reflect visual complexity of the task, with complexity generally greater in the visual than representational tasks. Finally, it is possible that task relevant information, such as letter or number identity in representational tasks, may recruit disparate brain areas such as those responsible for memory and language that are unlikely to play a role in processing abstract visual stimuli such as a line or greyscales stimulus.

The results of this study are therefore important for two reasons. First, they address the issue of whether pseudoneglect for mental representations of space is reduced in individuals with high levels of autistic-traits in line with the previously reported reduced pseudoneglect for physical space (English et al., 2015). Second, they provide new evidence concerning the question of whether common or disparate mechanisms underlie physical and representational pseudoneglect. To wit, if variations in levels of autistic-like traits produce similar variations in physical and representational pseudoneglect, this would provide suggestive evidence for common neural mechanisms. On the other hand, if pseudoneglect is not reduced for mental representations of space in individuals with high autistic-trait levels, it would suggest different mechanisms underlie spatial biases in physical and mental representations.
To address these questions, in the present work, we recruited two groups of neurotypical individuals with scores in the upper or lower third of the AQ distribution and measured their response biases on three tasks: greyscales and landmark tasks to observe levels of physical pseudoneglect, and a number line bisection task to observe levels of representational pseudoneglect. In line with our earlier findings, we expected reduced levels of physical pseudoneglect in our High AQ group compared to our Low AQ group (English et al., 2015) on both the greyscales and landmark tasks. This would be a replication and a critical extension of this earlier result to a novel task (landmark). If representational pseudoneglect is also attenuated in the group with higher AQ scores, this would provide the first evidence that autistic traits modulate not only physical but also representational pseudoneglect. This result would also provide evidence for a shared mechanism responsible for attenuation of both forms of pseudoneglect in High AQ (and possibly ASC) individuals.

Methods

Participants

Participants were 104 right-handed students recruited at the University of Western Australia. Students with AQ scores in the upper or lower third of a cohort that had completed the AQ in a previous screening procedure were invited to participate. Fifty-two participants were in each of the Low and High AQ groups.

Materials

All tasks and questionnaires were presented using Presentation software (Version 17.0, Neurobehavioral Systems) running on HP EliteOne 800 machines using 23” LCD monitors. Participants were seated approximately 50cm from the display.

Greyscales Task

Stimuli for this task were based on those previously used by English et al. (2015). Each trial consisted of two horizontal bars presented above and below the centre of the display. The shading on each bar changed from white to black incrementally along the horizontal azimuth, with one bar effectively being a reversal of the other (see Figure 3.2). The orientations of the bars were randomized such that the bar that was shaded from the left, white-to-black, was presented equally often as the

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1 No participant recruited for the study in the previous chapter participated in this study.
2 This recruitment method differs from that used in the previous chapter in order to maximise individual differences between the AQ groups, and allow for the study to be conducted with fewer participants.
Finally, one bar from each pair was shaded 'darker' than the other bar in the pair. This was achieved by randomly replacing 100 white pixels with black pixels on one bar, and conversely randomly replacing 100 black pixels with white pixels on the other bar, creating a 200-pixel difference in shading between the two bars.

**Figure 3.2.** An example of a stimulus presented in the greyscales task.

Each trial began with a fixation cross that was displayed for 1500ms before the greyscales stimuli were presented. Participants were instructed to observe the two bars and determine which of the two was 'darker' overall. Participants made their responses using the [T] and [B] keys on a standard keyboard, which indicated the "top" or "bottom" bar respectively. Participants had 5s from the onset of the greyscales stimuli to respond before the trial automatically ended. The task consisted of 120 trials, with factorial combinations of stimulus characteristics such as length and orientation counterbalanced across trials.

**Landmark Task**

Stimuli for this task consisted of a white horizontal bar presented in the centre of the display on a black background. The bar was 481 pixels (px) long and 10px wide and was bisected by a thin 1px wide, black vertical line. The position of the black line was randomized across trials, appearing in the true centre or 10px, 5px, 3px, 2px, or 1px to the left or right of centre. A mask consisting of randomly placed black and white pixels (white noise) covered the screen region occupied by the horizontal bar at the beginning of each trial for 1s to prevent participants from using positions on the previous trial when making judgements on the current trial.
Each trial began with a mask that was presented for 1000ms before the landmark stimuli appeared. Participants were required to decide whether the black vertical line on the white bar was closer to the left or right-hand side of the bar. Participants responded using the [Z] and [/] keyboard keys to indicate that they perceived the bisection to be closer towards the left or right-side of the bar respectively. Participants had 5s from the onset of the landmark stimuli within which to respond before the trial automatically ended. The task consisted of 132 trials, with the bisection appearing at all 11 locations an equal number of times.

**Number Line Task**

Stimuli for this task were adapted from those used by Loftus et al. (2009). Each trial consisted of a triplet of two-digit numbers, arranged with a central red number and two yellow flankers. There were four sets of flankers (19_55, 53_99, 42_98 and 17_83). For each set, the red central number was always shifted 1, 2 or 5 greater or less than the actual midpoint between the two flankers (e.g. for the flanker pair ‘19_55’, the midpoint is 37 and the possible central numbers included 32, 35, 36, 38, 39 and 42). Whereas the Loftus et al. study presented all numbers on the same horizontal plane, we used a diagonal configuration so that participants made top/bottom judgements instead of left/right judgements (see Figure 3.3). This change was made to dissociate participants’ potential bias towards making left/right key presses from left/right spatial judgements. Number triplets varied factorially with respect to the spatial configuration (spatially ascending/descending (SA/SD), left-to-right) and direction of numerical sequence (numerically ascending/descending (NA/ND), left-to-right). This resulted in four different possible spatial configurations for each triplet configuration (SA-NA, SA-ND, SD-NA, and SD-ND), four sets of flankers, and six possible values for the central number, yielding a total of 96 unique trials presented without repetition.
Figure 3.3. Examples of the four spatial configurations, with each configuration containing one, red central number and two, yellow flanker numbers. Left-to-right; A) spatially ascending, numerically ascending, B) spatially ascending, numerically descending, C) spatially descending, numerically ascending, D) spatially descending, numerically descending.

Each trial began with a centrally presented fixation cross which was displayed for 1000 ms, after which a number triplet was presented. Participants were required to determine if the top flanker or bottom flanker in a triplet was closer in numerical position to the red central number. Participants were instructed not to use arithmetic when making their judgements. Triplets were presented for 3 s, after which the triplet disappeared and participants had 2 s to make a response using the [T] and [B] keys to indicate “top” and “bottom” respectively. If a participant did not make a response within 2 s, the trial automatically ended.

Questionnaires

Levels of autistic-like traits were measured using the Autism Spectrum Quotient (Baron-Cohen et al., 2001), a 50-item self-report questionnaire that assesses autistic-like traits and behaviours in neurotypical individuals. Items were scored 1-4 using Austin’s (2005) method; higher scores represent more autistic-like traits. This scoring method was used rather than the 0-1 method reported by Baron-Cohen et al. (2001) to take advantage of the range of potentially useful information in each item and increase the variability of total AQ scores. Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971).

Procedure

Testing took place in a single session that typically lasted 45-60 minutes. At the beginning of the testing session, participants were given a verbal overview of the
testing procedure, including the general nature of the tasks and questionnaire involved. Participants then completed the three computer tasks in counterbalanced order across participants. Task-specific instructions were presented to participants on the computer immediately prior to commencing the relevant task. Participants also had the opportunity to complete a number of practice trials at the beginning of each task and take short breaks between tasks.

**Results**

Descriptive statistics for the High and Low AQ groups are presented in Table 3.1. Participant performance was screened for outliers on each of the tasks; if a participant was deemed an outlier for a particular task, their data were excluded from analysis only on that task. No participant was identified as an outlier on more than one task. We conducted one-tail t-tests on the differences in bias between AQ groups because we predicted a reduced left bias in our High AQ group given prior results (English et al., 2015).

**Table 3.1.** Characteristics of the Low AQ and High AQ comparison groups (standard deviations in parentheses).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Low AQ (n = 52, 5 male)</th>
<th>High AQ (n = 52, 18 male)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Age (years)</td>
<td>20.63 (4.25)</td>
<td>20.06 (3.39)</td>
</tr>
<tr>
<td>Mean AQ</td>
<td>89.60 (7.15)</td>
<td>120.04 (6.31)</td>
</tr>
</tbody>
</table>

The two groups did not differ in mean age ($p = 0.45$, $r = 0.07$), but the Low AQ group contained fewer male participants than the High AQ group [$\chi^2(1) = 9.43$, $p < 0.01$], and so we conducted preliminary versions of the analyses reported below with sex as an additional between-subjects variable to AQ group. No main effects of sex or interactions between sex and AQ group were reported on any of the task bias measures (all $p$'s > 0.13, all $\eta_p^2 < 0.02$). Given this result, we chose to conduct the following analyses without sex entered as a factor in order to focus on effects related to AQ group.

**Data Screening**

Several criteria were implemented to ensure that the participants were appropriately engaged with the tasks. Participants were excluded from the analysis of a single task if: A) more than a third of responses were faster than 200ms (indicating the
participant was anticipating target onset), B) the proportion of top/bottom key presses exceeded the group mean by more than 2.5 standard deviations for the greyscales or mental number line task or C) the proportion of left/right key presses for the two most extreme (and easiest) bisection locations exceeded the group mean by more than 2.5 standard deviations for the landmark task. One participant met criteria A (landmark task, High AQ), five participants met criteria B (greyscales task, two Low AQ; mental number line task, one Low AQ and two High AQ) and seven participants met criteria C (three Low AQ, four High AQ). No participant met exclusion criteria for multiple tasks. Finally, one participant was excluded from all analyses because her accuracy on multiple tasks was less than 50% (Low AQ), and one participant was excluded from the analysis for the mental number line task due to a data recording error (Low AQ).

**Greyscales Task**

Task accuracy was calculated as the percentage of trials for which a participant correctly identified the darker of the two bars on a given trial. Leftward spatial bias was calculated as the percentage of trials for which a participant selected the bar which had the darker end oriented towards the left-side of the screen (e.g. the top bar in Figure 3.2), regardless of whether the selected bar was actually darker overall.

Accuracy for both the Low AQ (M=56.23%, SD=6.17%) and High AQ group (M=57.38%, SD=6.66%) was above chance level (largest $p < 0.001$, smallest $r = 0.71$), with no difference between the groups ($p = 0.37$, $r = 0.09$). Pseudoneglect (leftward spatial bias) differed significantly from chance levels for the Low AQ group (M=60.38%, SD=18.23%; $p < 0.001$, $r = 0.50$), but only marginally so for the High AQ group (M=54.54%, SD=16.32%; $p = 0.05$, $r = 0.27$). Additionally, pseudoneglect was significantly higher in the Low AQ group relative to the High AQ group, $t(99) = 1.70, p = 0.046, r = 0.17$. Taken together, these results show an even stronger pattern than in our previous work (English et al., 2015), with only marginal levels of pseudoneglect seen in the High AQ group and a larger difference in pseudoneglect between AQ groups ($r=0.17$ vs. $r=0.12$ in our previous study). Greater levels of autistic traits in the High AQ group of the present study relative to the previous study might account for this stronger pattern (High AQ: $M = 120.04$ vs $M = 115.14$; see Cribb et al. (2016) for simulations of the influence of AQ group separation).

**Landmark Task**

Task accuracy was calculated as the percentage of trials on which participants correctly identified the location of the bisection towards the left or right side of the
horizontal bar, excluding trials where the bisection was presented at centre. Leftward spatial bias was calculated as the overall percentage of trials in which participants indicated that the bisection was closer to the right-side of the bar (as increased rightward responses suggest a relative perceptual exaggeration of the left side of space).

Accuracy for both the Low AQ (M=69.43%, SD=8.27%) and High AQ group (M=68.48%, SD=8.64%) was above chance level (largest $p < 0.001$, smallest $r = 0.91$), with no difference between the groups ($p = 0.59, r = 0.06$). Pseudoneglect differed significantly from chance levels in the Low AQ group (M=55.89%, SD=15.72%; $p = 0.01, r = 0.35$), but not in the High AQ group (M=50.57%, SD=15.15%; $p = 0.51, r = 0.04$). Additionally, pseudoneglect was significantly higher in the Low AQ group than in the High AQ group, $t(93) = 1.68, p = 0.048, r = 0.17$. Taken together, these findings suggest the Low AQ group showed pseudoneglect while the High AQ group did not, conceptually replicating findings using the greyscales task here and in our previous study (English et al., 2015).

**Number Line Task**

Response accuracy was measured as the percentage of trials on which participants correctly identified the flanker number that was closest in numerical position to the central number. A summary of the mean accuracy for each of the four configurations (illustrated in Figure 3.3) is provided in Table 3.2. A repeated measures analysis of variance (ANOVA) with the factors configuration type and AQ group revealed a main effect of configuration type on accuracy, $F(7,96) = 7.81, p < 0.001, \eta^2_p = 0.08$. However, there was no main effect of AQ group ($p = 0.60, \eta^2_p < 0.01$), or configuration x AQ group interaction ($p = 0.96, \eta^2_p < 0.01$). Accuracy for the Low AQ group (M=65.48%, SD=7.17%) and High AQ group (M=64.63%, SD=8.64%) were both above chance levels (largest $p < 0.001$, smallest $r = 0.86$), with no difference between the groups ($p = 0.89, r = 0.01$).

<table>
<thead>
<tr>
<th>Table 3.2. Number task accuracy across trial configurations (standard deviations in parentheses).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
</tr>
<tr>
<td>Low AQ</td>
</tr>
<tr>
<td>High AQ</td>
</tr>
</tbody>
</table>
Representational pseudoneglect (leftward representational bias) was calculated as the percentage of trials in which participants indicated that the flanker that was of a higher value was closer in numerical position to the central number. In the context of this study, in keeping with convention (Brooks et al., 2014), we refer to the numerically higher number as being positioned "rightward" of the central number, as the mental number line is considered to be a series of numbers that ascend in value from left-to-right. Therefore, an increased percentage of rightward responses would be indicative of exaggeration of the left side of the mental representation of the number line. Note that the words "left" or "right" in this task refer to a number’s position on the mental number line, not to its location on the display. To ensure that participants were not preferentially responding to the flanker number that was physically on the left side or right side of the screen, single-sample t-tests were conducted on both AQ groups to determine if responses to items presented on the left side of the screen differed from chance levels. Neither AQ group reported a significant bias towards flankers that were presented on one side of the screen (smallest $p = 0.44$, largest $r = 0.11$).

Representational pseudoneglect for both the Low AQ group (M=58.17%, SD=11.80%) and High AQ group (M=54.53%, SD=12.62%) exceeded chance levels (smallest $p = 0.01$, largest $r = 0.34$). There was no significant difference in the levels of representational pseudoneglect between AQ groups ($p = 0.21$, $r = 0.08$), which substantially differs from the results reported for the greyscales and landmark tasks, as well as our previous study (English et al., 2015), where physical pseudoneglect was attenuated in High AQ participants.

**Discussion**

The aim of this study was to determine if representational pseudoneglect is attenuated in a High AQ sample as has been reported for physical pseudoneglect (English et al., 2015). This was achieved by measuring response biases on tasks that require visual assessment of physical stimuli (the landmark and greyscales tasks), and a task that requires assessment of an internalized representation of space (the mental number line bisection task). If pseudoneglect were reduced for all tasks in the High AQ group relative to the Low AQ group, this would be evidence for a common neural mechanism underlying reduced pseudoneglect for physical and representational measures of space in individuals with high levels of autistic traits. However, if pseudoneglect were only reduced on the physical spatial tasks, and unaltered on the mental number line task, this would instead suggest that an attentional difference is
present in High AQ individuals that specifically affects attentional bias in processing of visually-presented stimuli.

Regarding physical pseudoneglect, the study has two key findings. First, it replicates our previous evidence for attenuated pseudoneglect amongst High AQ participants on a greyscale task (English et al., 2015). Second, it extends and generalize our previous findings by showing that physical pseudoneglect on the landmark task is also reduced in a High AQ group. This is particularly important, as it may have been possible that the attenuated pseudoneglect reported in the previous study was specific to the greyscale stimuli. To the contrary, the present results confirm that High AQ participants show a broad reduction in physical pseudoneglect relative to their Low AQ peers.

The results from the mental number line task answer two key questions about the relationship between AQ and representational pseudoneglect. First, whereas bias scores for the High AQ group did not significantly differ from chance levels on either measure of physical pseudoneglect, this was not the case for the number line task. Here, the High AQ group showed a significant level of representational pseudoneglect. Second, whereas physical pseudoneglect was reduced in the High AQ group relative to the Low AQ group for the landmark and greyscale task, levels of representational pseudoneglect were comparable between AQ groups in the number line task. Taken together, these results suggest high levels of autistic-like traits do not influence spatially-organized mental representations, indicating that unique mechanisms underlie physical and representational spatial biases in this group.

Why might pseudoneglect differ between physical and mental spatial representations for High AQ participants? The limited research into asymmetries in spatial attention with respect to ASC restricts our ability to form definite conclusions. However, one likely possibility is that attenuation of physical pseudoneglect arises from processes directly related to the visual processing system that are not involved in the number line task (which does not require judgements based on visual stimulus characteristics). It is well documented that attention-related visual processing in autism is markedly different than in neurotypical individuals. In particular, one of the most widely reported differences is with respect to the global and local processing of visually presented stimuli. Whereas most neurotypical individuals show a preference for processing visual stimuli in a holistic or global manner, ASC and High AQ individuals show a preference for a more piecemeal local processing style (Bayliss & Kritikos, 2011; Cribb et al., 2016; Grinter, Maybery, et al., 2009; Grinter, Van Beek, et al.,
2009; Rhodes et al., 2013; Russell-Smith et al., 2012; Sutherland & Crewther, 2010). This difference in preferential processing styles is particularly relevant here because, like pseudoneglect, global processing is linked to RH activation while local processing is associated with LH activation (Evans, Shedden, Hevenor, & Hahn, 2000; Flevaris, Bentin, & Robertson, 2010; Hübner & Studer, 2009; Lux et al., 2004; Malinowski, Hübner, Keil, & Gruber, 2002; Volberg & Hübner, 2004; Weissman & Woldorff, 2005; Yamaguchi, Yamagata, & Kobayashi, 2000).

Given this parallel, we tentatively hypothesize that differences in hemispheric activation in High AQ and ASC specifically affect processes related to visual attention and stimulus evaluation. On this notion, in the absence of the need to evaluate a visual stimulus, hemispheric activation biases do not affect performance. While this dissociation might reflect differences unique to High AQ and ASC, it may alternatively reflect similar mechanisms underlying dissociations in RH-damaged patients, where neglect on visual and representational tasks has not always been found to co-occur (Doricchi et al., 2005; Loetscher & Brugger, 2009; Loetscher et al., 2010; Pia et al., 2012; Rossetti et al., 2011; Storer & Demeyere, 2014; van Dijck et al., 2012). These dissociations may be driven by the activation of different regions depending on the physical or representational nature of the task. For example, line bisection judgements are associated with activation of the striate, extrastriate visual cortex and parietal lobes, with noted RH lateralization (Doricchi & Angelelli, 1999; Fink et al., 2000). However, judgements of number positioning are relatively less lateralized to the RH, and are associated with bilateral intraparietal sulcus activation, as well as activation in the left precentral gyrus and prefrontal areas (Dehaene, 2004; Dehaene, Piazza, Pinel, & Cohen, 2003; Doricchi et al., 2005; Walsh, 2003). If spatial attention shows reduced RH lateralization for individuals with high levels of autistic traits, these regional differences in activation may account for why we found differences in between the two AQ groups on physical but not representational pseudoneglect.

Overall, the absence of reduced representational pseudoneglect for High AQ individuals is evidence against the notion of a common mechanism underlying physical and representational pseudoneglect. What then, may account for the results of previous studies, that found that using TMS or tDCS to alter the activation of the posterior parietal cortex shifted attentional biases for physical and representational measures of space in the contralateral direction of the stimulated hemisphere (Göbel et al., 2006; Göbel, Walsh, & Rushworth, 2001; Loftus & Nicholls, 2012)? As mentioned earlier, while both task types are associated with parietal activation, several cortical
regions are only activated when completing either physical or representational spatial tasks specifically (Dehaene, 2004; Dehaene et al., 2003; Doricchi & Angelelli, 1999; Doricchi et al., 2005; Fink et al., 2000; Walsh, 2003). A potential explanation that is compatible with the account above is that stimulation of the PPC may lead to attentional changes for both task types, while other key structures are unaffected. This may be of key importance as unaffected structures might compensate for changes in parietal activity. For example, in the absence of external stimulation, relatively intact right prefrontal working memory structures, which are linked to building up the mental number line (Doricchi et al., 2005) may compensate for reduced parietal activation that is related to high levels of autistic traits.

To summarize, the purpose of this study was to determine if previously reported alterations in physical spatial bias found between AQ groups also occurred in spatially-organized mental representations, and to generalize our previous findings (English et al., 2015) using an alternative measure of attentional spatial bias (the landmark task). While we replicated the attenuation of physical pseudoneglect in High AQ participants on both tasks, Low and High AQ groups showed comparable representational pseudoneglect on the mental number line task. We also hypothesize that the PPCs play a specific role in processing physical spatial representations but not in tasks requiring judgements about mental spatial representations, thus potentially explaining task dissociations in our High AQ group. Finally, it should also be noted that although the findings of this study are likely to be indicative of what might be found in a clinical ASC sample, it is important to replicate our findings using such a sample in future work. While research into lateralization of spatial attention in regard to ASC is a relatively novel line of inquiry, atypical asymmetries are relatively simple to observe and, with further understanding of the underlying mechanisms, such measures could be valuable in the assessment and monitoring of neurological functioning in ASC.

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Reduced Pseudoneglect for Physical, Not Representational, Space in High AQ Adults

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Chapter Four

Modulation of global and local processing biases in adults with autistic-like traits

Michael C.W. English, Murray T. Maybery and Troy A.W. Visser

Previous work shows that doing a continuous performance task (CPT) shifts attentional biases in neurotypical individuals towards global aspects of hierarchical Navon figures by selectively activating right hemisphere regions associated with global processing. The present study examines whether CPT can induce similar modulations of attention in individuals with high levels of autistic traits who typically show global processing impairments. Participants categorized global or local aspects of Navon figures in pre- and post-CPT blocks. Post-CPT, high trait individuals showed increased global interference during local categorization. This result suggests that CPT may be useful for temporarily enhancing global processing in individuals with high levels of autistic traits and possibly those diagnosed with autism.

Autism is a disorder well-known to be characterized by repetitive patterns of behavior, restricted interests and impaired social functioning (American Psychiatric Association, 2000). Less well known is that autism is also commonly associated with a bias to preferentially process individual ("local") components over holistic ("global") constructs (Behrmann, Thomas, & Humphreys, 2006; Behrmann, Avidan, et al., 2006;
Isomura, Ogawa, Yamada, Shibasaki, & Masataka, 2014a, see Happé & Frith, 2006, for a review). For example, in the Embedded Figures Test (Witkin, 1971), which requires locating a smaller target shape (e.g., a triangle) that forms part of a larger, more complex image (e.g., a grandfather clock), individuals with autism spectrum conditions (ASC) are reliably faster at locating the smaller target than neurotypical individuals (for a meta-analysis see Muth, Hönekopp, & Falter, 2014). Similarly, for hierarchical figures – stimuli that consist of a larger character and multiple embedded characters (Navon, 1977) – individuals with ASC show faster identification of the smaller characters and/or slowed identification of the larger character compared to neurotypical individuals (also see Muth et al., 2014).

According to the “weak central coherence” theory (Shah & Frith, 1983), the enhanced ability to attend to local-level stimuli in ASC arises from an impairment in the usual automatic propensity to process information in a holistic fashion seen in neurotypical individuals. Consequently, when attending to local-level stimuli, individuals with ASC are less distracted by holistic, global-level inputs, leading to improved performance. However, when attending to global-level stimuli, the relatively weaker drive for coherence results in greater interference from local-level stimuli, leading to poorer performance. While Shah and Frith’s argument posits a potential deficit in global processing in ASC, many studies have found that individuals with ASC can actually process global information with comparable performance to neurotypical individuals, especially if their attention is explicitly directed to the global construct with a prime or instruction (López, Donnelly, Hadwin, & Leekam, 2004; Plaisted, Swettenham, & Rees, 1999). This suggests that rather than having a structural deficit in global processing, individuals with ASC simply display a preference for prioritizing local information.

The present work explores the possibility that processing in ASC could be shifted towards global constructs using a behavioral task that increases right hemisphere (RH) activation. There is substantial evidence that activation of cortical regions in the RH is associated with global processing (Evans, Shedden, Hevenor, & Hahn, 2000; Flevaris, Bentin, & Robertson, 2010; Hübner & Studer, 2009; Malinowski, Hübner, Keil, & Gruber, 2002; Volberg & Hübner, 2004; Weissman & Woldorff, 2005; Yamaguchi, Yamagata, & Kobayashi, 2000). Moreover, the RH has also been linked to variations in tonic (sustained) and phasic (short-term) attention. For example, increases in tonic attention lead to greater activation in the right inferior frontal, inferior parietal and anterior cingulate regions (Bartolomeo, 2014; Singh-Curry &
Husain, 2009; Sturm & Willmes, 2001; Thiel, Zilles, & Fink, 2004), while phasic attentional changes modulate activity in the right ventral fronto-parietal network and anterior cingulate (Corbetta & Shulman, 2002). Together, this suggests that a shift towards processing global constructs might be accomplished using a task that increases tonic and phasic awareness.

Recent work by Degutis and Van Vleet (2010) directly supports this suggestion. They had RH-damaged stroke patients complete a continuous performance task (CPT) over nine days that required participants to withhold a response to the presentation of pre-designated target images (teapots; 10% of trials), but to quickly respond to non-targets (all other objects; 90% of trials). This task is similar to the sustained attention to response task (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) in terms of response ratios, but differs in that the CPT used by Degutis and Van Vleet (2010) has variable and unpredictable inter-trial intervals, as opposed to fixed and predictable intervals. The combination of relatively rare inhibited responses and random inter-trial intervals demanded a high level of task engagement, thereby enhancing tonic and phasic attention. Consistent with the link between tonic/phasic attention and RH activity, left visuospatial neglect in the RH damaged stroke patients decreased following CPT but was unchanged by a similar training task that did not modulate tonic or phasic attention. Subsequently, Van Vleet, Hoang-duc, DeGutis, and Robertson (2011) showed that CPT training could also modulate global and local attentional biases to hierarchical figures (Navon, 1977) in a neurotypical sample. Following a brief period of CPT, participants were better able to ignore local distractors when directed to identify the global aspect of hierarchical stimuli, measured as a significant decrease in the difference between RTs to trials with and without the local distractor. Simultaneously, participants were worse at ignoring global distractors when tasked with identifying the local aspect. Again, these changes were not present following a training task that did not modulate tonic or phasic attention.

The work of Van Vleet and colleagues strongly suggests that behavioral training, in the form of a CPT task, can increase RH activation and global preference in RH-damaged and neurotypical individuals. However, no study, to our knowledge, has yet attempted to produce similar results using an ASC sample. Thus, we do not know if behavioral training can modulate attentional biases for individuals with ASC. It is entirely possible that processing preferences are relatively rigid for individuals with

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1 Approximately 10 minutes in duration.
ASC, and may exhibit resistance to behavioral training. However, in light of evidence linking atypical behaviors and functioning in ASC to cortical abnormalities specific to the RH (Di Martino et al., 2011; Jou, Minshew, Keshavan, Vitale, & Hardan, 2010; Lazarev, Pontes, & DeAzevedo, 2009; Orekhova et al., 2009; Ozonoff & Miller, 1996; Siegal, Carrington, & Radel, 1996), in the present work, we conducted two experiments to assess whether processing in individuals with high levels of autistic traits could be shifted towards a global aspect using CPT training to increase tonic and phasic attention.

In the first experiment, we began by replicating the experimental findings reported by Van Vleet et al. (2011) using a modified version of their paradigm adapted for our laboratory. This is critical not only because it shows the benefits of CPT are generalizable across laboratories and minor variations in methodology, but also because the experimental outcome provides a baseline against which to compare subsequent findings. In the second experiment, we sought to determine how CPT training influences global and local processing in neurotypical individuals with low or high levels of autistic traits. An increasing body of research has found that low and high autistic-trait comparisons reveal similar patterns of results as found in neurotypical and clinical ASC comparisons, especially with regard to global/local processing (for a meta-analysis see Cribb et al., 2016; see also: Bayliss & Kritikos, 2011; Grinter, Van Beek, et al., 2009; Grinter, Maybery, et al., 2009; Rhodes et al., 2013; Russell-Smith et al., 2012; Sutherland & Crewther, 2010). Thus, we expected the findings here to provide broad indications about the effectiveness of CPT training in altering local processing biases in neurotypical individuals high in autistic traits, and potentially by extension, individuals with ASC.

**Experiment 1**

In this experiment, we aimed to replicate the main findings presented by Van Vleet et al. (2011). To achieve this, we modified the experimental procedure laid out by these authors using our own stimuli and equipment. Participants began by categorizing the global and local aspects of a series of hierarchical figures (e.g. Figure 4.1; Navon, 1977) to obtain measures of task interference in global-categorization and local-categorization task conditions. Task interference was calculated by taking the difference in RTs between trials that were “congruent” (i.e. the global and local aspect

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2 Modified in the sense that while we recreated the experiment based on the parameters outlined by Van Vleet et al. (2011) to the best of our ability, the experiments may not be exactly identical. No intentional modifications were made.
of the hierarchical figure were the same category – both numbers or both letters) and trials that were “incongruent” (i.e. the global and local aspect of the hierarchical figure were different categories – one letters and the other numbers). This difference provides a measure of how well individuals can maintain their attention on the aspect of the hierarchical figure that they were instructed to attend to. Larger interference scores, corresponding to longer RTs on incongruent trials relative to the congruent trials, therefore represent a relatively greater tendency to attend to the to-be-ignored aspect of the task.

Figure 4.1. Examples of hierarchical figures (Navon, 1977) adapted from Van Vleet et al. (2010); the two on the left are form-congruent (the global and local features are the same; both letters or both numbers) and the two on the right are form-incongruent (the global and local features are mismatched; letters and numbers are simultaneously present.

Participants then completed training consisting of the CPT, or a categorization control task (CCT) that used similar stimuli but does not invoke changes to tonic/phasic attention (Van Vleet et al., 2011). Finally, participants repeated the hierarchical figures task to assess changes in global and local processing. We predict that, following a period of CPT, participants' attention to global details will be relatively greater than prior to training; specifically, local interference for global-categorization should be reduced, and global interference for local-categorization should be increased. In contrast, participants who complete CCT should experience no significant changes in interference for either categorization type.

Method

Participants

Seventy-two first year psychology students (CPT group: n=36 (10 male), mean age 18.39 (SD=1.59); CCT group: n=36 (18 male), mean age 19.31 (SD=2.75)) at the University of Western Australia participated in the study in exchange for partial credit
towards a course requirement. Participants were selected to complete either the CPT or CCT by order of attendance to the laboratory.

**Materials**

Participants were seated approximately 500mm in front of BenQ XL2420T displays (refreshing at 100 Hz) that were connected to computers running Windows 7. Presentation 17.0 software (Neurobehavioral Systems) was used to generate and display task stimuli and record participant responses.

The Hierarchical Figure Task (HFT)

Stimuli comprised the letters A, E, F, H, L and P, and the numbers 2, 3, 4, 6, 7 and 9. For each stimulus, one letter or number was randomly chosen as the larger global form and was created using a different randomly-chosen smaller letter or number as the local form arranged on a 4x5 grid (see Figure 4.1). Every combination of letters and numbers as the global and local forms was used to create 132 figures. Half of the figures were congruent, with global and local forms chosen from the same category (i.e., global letter constructed from local letters, or global number constructed from local numbers), while the other half were incongruent, with the global and local forms chosen from different categories (i.e., global letter constructed from local numbers or vice-versa).

The task was divided into two blocks, with participants required to categorize (letter or number) the global form in one, and categorize the local form in the other. The blocks were presented in counterbalanced order. Each unique hierarchical figure was presented twice, yielding 264 trials per block. In the global-categorization block, the hierarchical figure’s global forms were 1.90° wide x 2.53° high and were created using font size 10 characters. In the local-categorization block, the hierarchical figure’s global forms were 1.43° wide x 1.90° high and were created using font size 9 characters. In a pilot study, Van Vleet et al. (2011) found that these stimulus sizes produced optimal interference from the task-irrelevant global or local form.

Each trial began with a fixation cross presented in the center of the display for 500ms, followed by a hierarchical figure presented for 750ms, and then a blank screen. Participants were directed to categorize either the global or local form of the hierarchical figure using two keys on a keyboard - the ‘Z’ key if the target form was a letter or the ‘/’ key if the target form was a number. Participants were prompted to make their responses as quickly as possible whilst also retaining high task accuracy. Responses could be made during the presentation of the hierarchical figure or the
blank screen, with a response immediately ending the trial. The fixation cross then reappeared marking the start of the next trial.

Continuous Performance Task (CPT)

The CPT task was based on the paradigm previously used by Degutis and Van Vleet (2010), and Van Vleet et al. (2011). Task stimuli were 90 images (6.97° wide x 3.49° high) selected from the Caltech-256 Object Category dataset (Griffin, Holub, & Perona, 2007), which was used due to the diverse nature of the images in the dataset, and was also the source of CPT stimuli in Degutis and Van Vleet (2010), and Van Vleet et al. (2011). Eight of the images were of teapots and were designated as targets, while the remaining 82 images were distractors comprised of random, everyday objects. Participants were instructed to withhold responses to target images, whilst dismissing all non-targets with a response.

Each trial began with a fixation cross presented in the center of the display for 600, 1800 or 3000ms (randomly chosen on each trial) to prevent participants from anticipating the onset of the image. An image then replaced the fixation cross and remained onscreen for 500ms or until a response was recorded. Participants were directed to press a response key (either 'Z' or '/') as quickly as possible if a distractor image appeared, but to withhold a response if a target image (a teapot) appeared and wait for the image to disappear. Images were presented in random order, with each image appearing four times, yielding 360 trials. The task took participants approximately 16 minutes to complete.

Continuous Categorization Task (CCT)

The CCT required participants to view a series of images and respond to each by indicating its orientation. Images were identical to those used in the CPT, except that 50% of the images (randomly-chosen) were inverted prior to presentation. Stimulus presentation conditions were also identical to the CPT. However, participants were directed to make a non-speeded orientation response when an image was displayed, pressing the 'Z' key if the image was upright, or the '/' key if the image was inverted. The equal frequencies of presentation of upright and inverted images and non-speeded responses result in a task that is less focused on tonic and phasic modulations of attention than the CPT.

Procedure

The experimental structure was broken into three main parts. Participants began with two HFT blocks (pre-training), which were followed by the CPT or CCT, and
then two further HFT blocks (post-training). To control for task order effects, the four possible orders in which HFT blocks (local vs. global classification) could be completed were counterbalanced across participants. Participants received instructions for all tasks at the beginning of the experimental session and were also presented with task-specific instructions on the computer immediately before beginning each task. In addition, each task began with 40 practice trials so that participants could adjust to the task demands.

Results

Training Task Performance

Participants who completed the CPT responded to non-targets with a mean RT of 376ms (SD=26ms), missed responding to 15.95% (SD = 10.06%) of non-targets, and incorrectly responded (false alarm) to 40.54% (SD=15.13%) of target images. Participants who completed the CCT had comparable accuracy for upright and inverted images (respectively, M=93.69%, SD=4.68% and M=94.11%, SD=4.29%).

General Hierarchical Figure Task Performance

Trials for the Hierarchical Figure Task were excluded from the calculation of interference scores if they were outside the range of the mean RT ± 3SD for a given participant (if the lower bound of the acceptable range fell below 200ms for a participant, the lower bound was set to 200ms). Additionally, RT analyses excluded incorrect trials.

Hierarchical Figure Task accuracy was examined using a Training Group (CPT vs CCT) x Session (pre- vs post-training) x Categorization Type (global-categorization vs local-categorization) repeated measures analysis of variance (ANOVA). The results are summarized in Table 4.1. A main effect of Session was found, $F(1, 35) = 16.37, p < 0.001, \eta_p^2 = 0.19$, which indicated that accuracy was lower across tasks in the post-training session. A main effect of Categorization Type was also present, $F(1, 35) = 5.63, p = 0.02, \eta_p^2 = 0.07$, which indicated that participants completed the local-categorization task with greater accuracy than the global-categorization task$^3$. No other

$^3$ It should be acknowledged that, as outlined earlier, neurotypical participants show superior performance for global processing relative to local processing. However, this is not always the case and certain experimental manipulations can change this pattern of performance. For example, as mentioned later in the General Discussion, alterations of the width of the attentional spotlight can affect performance. In the present study, it may be that the use of a small fixation cross presented before the hierarchical figure stimuli primed attention towards the local level, resulting in overall superior local performance. Importantly, this does not affect the results of the interference produced, the main aspect of this study.
significant main effects or interactions were obtained. This suggests that HFT accuracy was comparable for the CPT and CCT groups, meaning that potential differences found in RTs between the groups is likely the result of different training conditions.
Table 4.1. Hierarchical figure task performance (means and SDs) for global and local-categorization summarized across Session (pre- and post-training), Training Group (CPT and CCT) and, for reaction times, congruency (congruent (c) and incongruent (i)) (standard deviations in parentheses).

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th></th>
<th>Reaction Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-CPT</td>
<td>Post-CPT</td>
<td>Pre-CPT (c)</td>
</tr>
<tr>
<td>Global Categorization</td>
<td>92.03% (3.60%)</td>
<td>90.47% (4.15%)</td>
<td>618 (112)</td>
</tr>
<tr>
<td>Local Categorization</td>
<td>92.86% (2.99%)</td>
<td>91.39% (3.94%)</td>
<td>576 (84)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Pre-CCT</th>
<th>Post-CCT</th>
<th>Pre-CCT (c)</th>
<th>Pre-CCT (i)</th>
<th>Post-CCT (c)</th>
<th>Post-CCT (i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Categorization</td>
<td>92.36% (4.16%)</td>
<td>91.11% (4.40%)</td>
<td>582 (73)</td>
<td>605 (74)</td>
<td>522 (60)</td>
<td>541 (61)</td>
</tr>
<tr>
<td>Local Categorization</td>
<td>92.58% (4.31%)</td>
<td>91.92% (3.94%)</td>
<td>546 (94)</td>
<td>554 (77)</td>
<td>510 (63)</td>
<td>522 (62)</td>
</tr>
</tbody>
</table>
Identical analyses were conducted on HFT RTs. A main effect of Session was found, $F(1, 35) = 88.76, p < 0.001, \eta_p^2 = 0.56$, with RTs faster during the post-training session. A main effect of Categorization Type was also present, $F(1, 35) = 17.58, p < 0.001, \eta_p^2 = 0.20$, with RTs faster for local-categorization compared to global-categorization. A Session x Categorization Type interaction was present, $F(1, 35) = 19.23, p < 0.001, \eta_p^2 = 0.22$, which indicated that RTs for global-categorization were slower relative to local-categorization prior to training, but were comparable following training. Finally, a Training Group x Categorization Type interaction was also found, $F(1, 35) = 4.02, p = 0.05, \eta_p^2 = 0.05$, though interpretation of this interaction is not particularly germane to the present study given that RTs were collapsed across pre- and post-training sessions.

**Global/Local interference changes following training**

Finally, to determine if CPT or CCT influenced participants’ ability to direct their attention to the global or local aspect of the hierarchical figure, task RTs were then subjected to further analysis to examine differences in HFT stimuli with congruent or incongruent global and local levels between CPT and CCT training groups, and pre- and post-training sessions (see Table 4.1). To determine the specific effect of CPT or CCT training on the ability to focus on relevant global or local forms, global and local interference scores were then calculated from the raw RTs. A measure of local interference was created by subtracting RTs on global-categorization congruent trials from RTs on global-categorization incongruent trials. A measure of global interference was calculated by subtracting RTs on local-categorization congruent trials from RTs on local-categorization incongruent trials. Interference scores were calculated separately for pre- and post-training sessions, and then were contrasted with each other to determine the impact that CPT or CCT training had on participants’ ability to ignore the distracting information presented at either the local or global level.

Levels of task interference are summarized in Figure 4.2. Change in task interference following attentional training was assessed using a Training Type (CPT vs CCT training) x Categorization Type (local vs global-categorization) x Session (pre- vs post-training) x Categorization Order (global-categorization first vs local-categorization first in post-training test blocks) mixed-design analysis of variance (ANOVA). The Categorization Order variable was included to evaluate Van Vleet et al.’s (2011) suggestion that training effects may be short-lived and thus only present in the first post-training HFT block. A main effect of Categorization Type was revealed, $F(1, 68) = 4.42, p = 0.04, \eta_p^2 = 0.06$, which indicated that greater levels of interference were
present during the global task relative to the local task across all conditions. The ANOVA also revealed a significant interaction between Session and Categorization Type, $F(1, 68) = 8.36, p < 0.01, \eta^2_p = 0.11$, indicating that interference levels for global and local-categorization showed substantially dissimilar changes as a result of attentional training. The ANOVA revealed no other main effects or interactions (all $p$s > 0.06, all $\eta^2_p < 0.06$).

Figure 4.2. Interference pre- and post-training for each training condition (error bars represent mean standard error. Paired sample t-tests with $p$s < 0.05 indicates with a *).

The absence of a Training Type x Categorization Type x Session interaction suggests that effects did not differ across different types of training. However, examination of Figure 4.2 appears to indicate that while training effects had a similar pattern across conditions, effects were more pronounced in the CPT compared to the CCT condition. For this reason, we also conducted two follow-up ANOVAs on the CPT and CCT data separately, following the analytical procedure of Van Vleet et al. (2011). The notable result of these additional analyses was a significant Categorization Type x Session interaction that was present in the CPT training condition only, $F(1, 35) = 8.20, p < 0.01, \eta^2_p = 0.19$, and not in the CCT training condition, $F(1, 35) = 1.82, p = 0.19, \eta^2_p = 0.05$.

Finally, in keeping with Van Vleet et al.'s (2011) analytical procedure, a priori t-tests were conducted to examine potential changes in task interference as a result of attentional training. A paired samples t-test on the global-categorization task comparing pre- and post-CPT performance revealed a significant decrease in local
interference following CPT training, $t(35) = 2.27, p = 0.03$. An identical $t$-test on the local-categorization task revealed a significant increase in global interference following CPT training, $t(35) = 2.17, p = 0.04$. In contrast, identical analyses comparing pre- and post-CCT performance showed no changes (both $p_s > 0.34$, both $r_s < 0.09$).

Discussion

The present experiment successfully replicated the chief findings of Van Vleet et al. (2011) using our own equipment and modified experimental design. Similar to their study, following CPT training, there was a significant increase in global interference and a significant decrease in local interference for the local and global-categorization tasks respectively. Importantly, similar changes were not reported in the CCT group, indicating that the increased tonic and phasic attention were responsible for shifts in global preference rather than general characteristics of the task or stimuli. In short, the results validate our instantiation of the CPT training, replicate the benefits to global processing found in previous work, and provide a useful baseline against which to judge performance in Experiment 2.

That said, our results did depart from Van Vleet et al.'s (2011) in one respect. While they found the effects of CPT training dissipated after a single block of trials, training effects in our experiment persisted throughout the HFT. Participants in both studies completed a similar number of training trials, so this difference cannot be explained in terms of training length. However, it does appear that there were differences in engagement with the CPT training between the studies. Specifically, our participants made faster responses to non-target images (376 vs 462ms) at the cost of reduced correct response omissions to target images (59 vs 77%). This suggests that a focus on making speeded responses in the CPT task, presumably reflecting a relative reduction in inhibition to targets, leads to a relatively larger global shift observed post-training.

**Experiment 2**

As outlined earlier, neurotypical individuals high in autistic-like traits and those with ASC both show an atypical bias towards local processing relative to their neurotypical, low autistic trait peers (for a meta-analysis see Cribb et al., 2016; see also: Bayliss & Kritikos, 2011; Grinter, Van Beek, et al., 2009; Grinter, Maybery, et al., 2009; Rhodes et al., 2013; Russell-Smith et al., 2012; Sutherland & Crewther, 2010). In this experiment, using the same paradigm as in Experiment 1, we aimed to determine whether CPT training increases global processing in neurotypical individuals with high
levels of autistic traits, and compare this to effects on individuals with low levels of autistic traits. This study may be the first to show that behavioral training designed to increase RH functioning can shift processing towards global constructs in individuals high in autistic-like traits. It would also provide preliminary insight into potential effects of training on a clinical ASC sample.

Method

Participants

Participants were 128 right-handed, first-year psychology students at the University of Western Australia who participated in the study in exchange for partial credit towards a course requirement. Because non-right-handed individuals show reduced lateralization of brain functions (Banich, 1997), we recruited only right-handed participants to ensure that any atypical lateralization reflected the contribution of autistic traits only. A measure of autistic traits, the Autism-spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) was obtained in a separate screening procedure completed by the entire first-year cohort, and participants were invited to the study if their AQ scores were in the upper or lower quartile of the cohort. Participants were selected to complete either the CPT or CCT by order of attendance to the laboratory. No participants had completed Experiment 1. Descriptive statistics for the participants are summarized in Table 4.2.

Table 4.2.

Descriptive statistics for participants in Experiment 2 (standard deviations in parentheses)

<table>
<thead>
<tr>
<th></th>
<th>CPT</th>
<th></th>
<th>CCT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low AQ</td>
<td>High AQ</td>
<td>Low AQ</td>
<td>High AQ</td>
</tr>
<tr>
<td>N</td>
<td>32; 7 male</td>
<td>32; 12 male</td>
<td>32; 6 male</td>
<td>32; 5 male</td>
</tr>
<tr>
<td>Age</td>
<td>19.63 (4.38)</td>
<td>21.69 (7.46)</td>
<td>22.56 (8.95)</td>
<td>19.16 (1.44)</td>
</tr>
<tr>
<td>AQ</td>
<td>89.91 (6.55)</td>
<td>125.47 (6.71)</td>
<td>90.28 (7.35)</td>
<td>127.17 (8.30)</td>
</tr>
</tbody>
</table>

Materials

Experiment 2 used the same materials as Experiment 1 with the addition of the AQ (Baron-Cohen et al., 2001), and the Edinburgh Handedness Inventory (EHI; Oldfield, 1971). The AQ is a 50-item self-report questionnaire that assesses traits and characteristics associated with autism in neurotypical individuals. Items were scored
using the 1-4 method described by Austin (2005) with higher scores indicating greater levels of autistic-like traits. This scoring method was used to take advantage of the range of potentially useful information in each item, increasing the variability of total AQ scores. The EHI is a 10-item self-report questionnaire used to assess handedness of participants.

Procedure

Apart from the preliminary screening with the AQ and EHI, the procedure was identical to that of Experiment 1.

Results

Training task performance

Low and High AQ performance on the CPT and CCT was comparable (summarized in Table 4.3), with independent samples t-tests comparing response times, misses and false alarms showing no significant differences between the groups (all ps > 0.33, all rs < 0.04).

<table>
<thead>
<tr>
<th></th>
<th>Low AQ</th>
<th>High AQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction Time (non-targets)</td>
<td>379ms (23ms)</td>
<td>376ms (29ms)</td>
</tr>
<tr>
<td>Misses (non-targets)</td>
<td>14.95% (8.47%)</td>
<td>14.04% (11.94%)</td>
</tr>
<tr>
<td>False Alarms (targets)</td>
<td>42.76% (15.67%)</td>
<td>46.75% (17.07%)</td>
</tr>
<tr>
<td>CCT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy (upright)</td>
<td>81.10% (16.76%)</td>
<td>79.48% (19.47%)</td>
</tr>
<tr>
<td>Accuracy (inverted)</td>
<td>82.75% (17.67%)</td>
<td>84.88% (11.53%)</td>
</tr>
</tbody>
</table>

General Hierarchical Figure Task Performance

Similar to the first experiment, trials for the Hierarchical Figure Task were excluded from the calculation of interference scores if they were outside the range of the mean RT ± 3SD for a given participant (if the lower bound of the acceptable range fell below 200ms for a participant, the lower bound was set to 200ms). Additionally, RT analyses excluded incorrect trials.
Hierarchical Figure Task accuracy was examined using a Training Group (CPT vs CCT) x AQ Group (Low vs High AQ) x Session (pre- vs post-training) x Categorization Type (global-categorization vs local-categorization) repeated measures ANOVA, with results summarized in Table 4.4. A main effect of Session was found, $F(1, 124) = 34.22, p < 0.001, \eta^2_p = 0.22$, which indicated that accuracy was lower in the post-training session. No other effects reached significance (all $p$s $> 0.10$, all $\eta^2$s $< 0.02$). Critically, HFT accuracy for the CPT and CCT groups is comparable between training groups and AQ groups across the session, meaning that any differences in RTs are the result of different training tasks.
Table 4.4. Hierarchical figure task performance (means and SDs) for global and local-categorization summarized across Session (pre- and post-training), Training Group (CPT and CCT), AQ Group (Low and High AQ) and, for reaction times, congruency (congruent (c) and incongruent (i)) (standard deviations in parentheses).

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Reaction Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-CPT</td>
<td>Post-CPT</td>
</tr>
<tr>
<td>Global Categorization</td>
<td>Low AQ</td>
<td>92.73% (4.08%)</td>
</tr>
<tr>
<td></td>
<td>High AQ</td>
<td>91.20% (6.99%)</td>
</tr>
<tr>
<td>Local Categorization</td>
<td>Low AQ</td>
<td>93.07% (3.42%)</td>
</tr>
<tr>
<td></td>
<td>High AQ</td>
<td>92.31% (5.80%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Pre-CCT</th>
<th>Post-CCT</th>
<th>Pre-CCT (c)</th>
<th>Pre-CCT (i)</th>
<th>Post-CCT (c)</th>
<th>Post-CCT (i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Categorization</td>
<td>Low AQ</td>
<td>92.41% (4.38%)</td>
<td>614 (98)</td>
<td>633 (96)</td>
<td>546 (77)</td>
<td>555 (83)</td>
</tr>
<tr>
<td></td>
<td>High AQ</td>
<td>91.51% (4.90%)</td>
<td>599 (104)</td>
<td>617 (112)</td>
<td>524 (91)</td>
<td>542 (91)</td>
</tr>
<tr>
<td>Local Categorization</td>
<td>Low AQ</td>
<td>92.64% (4.59%)</td>
<td>557 (70)</td>
<td>573 (73)</td>
<td>525 (77)</td>
<td>542 (80)</td>
</tr>
<tr>
<td></td>
<td>High AQ</td>
<td>91.08% (4.96%)</td>
<td>551 (76)</td>
<td>564 (81)</td>
<td>539 (94)</td>
<td>549 (92)</td>
</tr>
</tbody>
</table>
Identical analyses were conducted on HFT RTs. A main effect of Session was found, $F(1, 124) = 110.01, p < 0.001, \eta^2_p = 0.47$, with RTs significantly faster during the post-training session. A main effect of Categorization Type was also present, $F(1, 124) = 14.36, p < 0.001, \eta^2_p = 0.10$, with faster responses recorded for the local-categorization task. A Session x Categorization Type interaction effect was found, $F(1, 124) = 19.49, p < 0.001, \eta^2_p = 0.14$, which indicated that participants were initially slower on global-categorization prior to training, but performed both categorization tasks comparably in the post-training session. Further statistically significant effects included a Categorization Type x Session x AQ Group interaction, $F(1, 124) = 4.18, p = 0.04, \eta^2_p = 0.03$, as well as a Categorization Type x Session x Training Group interaction $F(1, 124) = 10.37, p < 0.01, \eta^2_p = 0.08$. The first interaction indicated that both AQ groups performed similarly on both categorization tasks, except prior to training when the Low AQ group was slower at the local-categorization task. The second interaction indicated groups receiving CPT and CCT training performed similarly on both categorization tasks, except prior to training when the CPT group was slower at the local-categorization task. Finally, a Categorization Type x AQ Group x Training interaction was found, $F(1,124) = 11.73, p < 0.01, \eta^2_p = 0.09$, but was not examined further as the effects were meaningless due to the collapsing of pre- and post-training RTs for this comparison.

**Global/Local interference changes following training**

Finally, to determine if CPT or CCT influenced participant’s ability to direct their attention to the global or local aspect of the hierarchical figure in the presence of competing information from the to-be-ignored aspect, task RTs were subject to further analysis to examine differences in HFT stimuli with congruent or incongruent global and local levels between CPT and CCT training groups, between AQ groups, and pre- and post-training sessions (see Table 4.4). Global and local task interference was calculated in the same way as detailed in Experiment 1 to compare the effects of CPT and CCT training on the ability to focus on relevant global or local forms across AQ groups. Before conducting the critical analysis, a preliminary analysis was conducted to determine if pre-CPT training differences existed between the AQ groups using a repeated measures ANOVA with the factors Categorization Type (local vs global) and AQ Group (Low vs High AQ). If pre-existing differences between the AQ groups were present, it could affect the interpretation of subsequent analyses. The only statistically significant result from the analysis was a main effect of AQ Group, $F(1, 62) = 4.81, p = 0.03, \eta^2_p = 0.07$, indicating that interference was greater for the Low AQ group relative
to the High AQ group across both global and local-categorization. The other effects did not reach statistical significance (both \( p > 0.09 \), both \( \eta^2 \)s < 0.05).

Levels of task interference are illustrated in Figure 4.3. Changes in task interference following attentional training was assessed using a Training Type (CPT vs CCT) x Categorization Type (local vs global) x Session (pre- vs post-training) x AQ Group (Low AQ vs High AQ) x Categorization Order (global-categorization first vs local-categorization first in post-training test blocks) mixed-design ANOVA. Replicating the results of Experiment 1, a significant interaction was found between Session and Categorization Type, \( F(124, 1) = 4.26, p = 0.04, \eta^2 = 0.03 \), indicating that interference changed following attentional training. All other comparisons were non-significant (all \( p > 0.19 \), all \( \eta^2 = 0.01 \)).
Figure 4.3. Pre- and post-CPT and CCT training for the Low and High AQ groups (error bars represent mean standard error). Paired sample t-tests with ps < 0.05 indicates with a *.

AQ group was not found to interact with any of the variables and the critical Training Type x Categorization Type x Session x AQ Group interaction only reached $p = 0.51$, $\eta^2_p < 0.01$. However, as noted earlier, baseline levels of CPT differed between AQ Groups, which may have masked subsequent interaction effects. Furthermore, the results of Experiment 1 demonstrated that similarities in training effects across the two training tasks obscured otherwise significant interactions in the CPT condition. As such, and in keeping with Van Vleet et al.’s (2011) analytical procedure, a priori t-tests were conducted to determine if CPT training yielded interference changes similar to Experiment 1 for each of the AQ groups; specifically, if CPT reduced local interference for global-categorization, and increased global interference for local-categorization. In
the Low AQ group, local interference on the global-categorization HFT decreased following CPT training, \( t(31) = 2.05, p < 0.05, r = 0.25 \), while global interference on the local-categorization task did not change (\( p = 0.64, r = 0.07 \)). In the High AQ group, global interference on the local-categorization HFT increased following CPT training, \( t(31) = 2.28, p = 0.03, r = 0.22 \), while local interference on the global-categorization HFT showed no change (\( p = 0.84, r = 0.02 \)). Follow-up tests to examine the specific changes in interference following CCT training failed to reveal any significant differences between AQ groups (all ps > 0.14, all rs < 0.18).

**Discussion**

The chief aim of this experiment was to determine whether CPT training could modulate global processing bias in individuals high in autistic-like traits and to compare these changes to those seen in individuals low in autistic-like traits. As in earlier studies using RH-damaged and neurotypical participants, there was substantial evidence that CPT training shifted processing towards a global aspect in both Low and High AQ participants. This is consistent with the suggestion that CPT increases RH activation via changes in tonic and phasic attention. However, Low and High AQ individuals did not show the same pattern of benefits from CPT-training. Specifically, the Low AQ group showed only a decrease in local interference during global-categorization, while the High AQ group showed only an increase in global interference during local-categorization.

It should also be noted that, as in Experiment 1, the Categorization Order variable did not influence the pattern of results. This is a positive outcome, as it indicates that CPT training benefits may persist for significantly longer than found by Van Vleet and colleagues. Also, as in Experiment 1, we found that our participants completed the CPT with faster RTs and fewer correct response omissions to target images compared to Van Vleet et al.’s (2011) participants. This provides further evidence that emphasizing response speed over accurately withholding responses to items to be ignored may prolong the effects of CPT training on global processing bias.

**General Discussion**

ASC is associated with a preference for processing stimuli in a manner that emphasizes the local features relative to the global, coherent aspect (Behrmann, Thomas, & Humphreys, 2006; Behrmann, Avidan, et al., 2006; Isomura, Ogawa, Yamada, Shibasaki, & Masataka, 2014a, see Happé & Frith (2006) for a review). Importantly, this processing bias seems to be associated with the social processing
deficits that characterize the disorder. For example, greater difficulty on face and emotion recognition tasks has been linked to a reduced preference for globally organized stimuli (Behrmann, Avidan, et al., 2006; Gross, 2005; Rutherford & McIntosh, 2007; Walsh, Vida, & Rutherford, 2014).

The present investigation stems from studies that associate global processing with regions primarily located in the RH (Evans et al., 2000; Flevaris et al., 2010; Hübner & Studer, 2009; Lux et al., 2004; Malinowski et al., 2002; Volberg & Hübner, 2004; Weissman & Woldorff, 2005; Yamaguchi et al., 2000) and evidence linking atypical behaviors and functioning in ASC to cortical abnormalities specific to the RH (Di Martino et al., 2011; Jou et al., 2010; Lazarev et al., 2009; Orekhova et al., 2009; Ozonoff & Miller, 1996; Siegal et al., 1996). The goal of the present work was to determine whether global processing could be increased in neurotypical individuals with high levels of autistic traits using CPT training (Van Vleet et al., 2011). This task increases tonic and phasic attention and thus is thought to boost RH activation (Bartolomeo, 2014; Corbetta & Shulman, 2002; Singh-Curry & Husain, 2009; Sturm & Willems, 2001; Thiel et al., 2004).

In Experiment 1, we replicated the results of Van Vleet et al. (2011) using a modified experimental design with an unselected neurotypical sample. This allowed us to verify our methodology and ensured that the results from Experiment 2, which included separate groups of Low and High AQ neurotypical individuals, could be directly attributed to variations in autistic traits rather than any variations in methodology from prior work. Indeed, in Experiment 2, consistent with the possibility that CPT increases global processing, we found that the High AQ group showed increased global interference on the local-categorization HFT.

While the key finding from the present experiments is that CPT increased global preference in neurotypical participants who were high in autistic-like traits, it is interesting that this change manifested itself exclusively in increased global interference in the local-categorization condition. This contrasts with the pattern shown in the Low AQ group who manifested increased global preference as decreased local interference in the global-categorization condition. The differential effects of CPT training for the two forms of categorization across the Low and High AQ groups could be due to differences in pre-training performance across AQ groups. Because of this group difference in pre-CPT interference, it was comparatively more difficult to detect a significant increase in already-high global interference for the Low AQ group and a significant decrease in already-low local interference in the High AQ group following
CPT training. However, if pre-training differences were not present, as was the case between AQ groups in the CCT condition, it is possible that CPT effects on local and global categorization would have been similar for the two AQ groups if baseline interference levels had been comparable. Given the absence of ASC-related research in regard to behavioral training of global and local processing, at this point in time there is no strong prior basis for a particular profile of attentional training effects for the different AQ groups. Regardless, the fact that CPT was effective at increasing global interference for local categorization, and the potential remains for CPT to be effective at reducing levels of local interference for global categorization, highlights the need for further investigations in this area.

That said, other options aside from pre-training group differences could also account for this pattern of results. For example, the impact of CPT could differ across AQ groups. However, for this dissociation to be true, it would require that CPT-related changes of decreased local interference during global-categorization and increased global interference during local-categorization to be attributed to two different mechanisms, with one operating in Low AQ participants and the other in High AQ participants. Perhaps this notion could be plausible if there were indication that CPT affected attention to both globally and locally presented stimuli, but this is unlikely given prior evidence that it selectively activates RH regions, which are more likely to be substantially involved in global rather than local processing.

Another possibility is that significant differences in both global and local interference across AQ groups would have been found with additional CPT training. Here, we used a single 16-minute session of CPT as outlined in Van Vleet et al. (2011) as it was sufficient to produce a measurable change in a neurotypical group. However, in Degutis and Van Vleet’s study (2010) with neglect patients, a decrease in left neglect severity was observed after a much longer training regimen consisting of nine days of 36 minute sessions. Given that several papers have suggested that individuals with ASC may also have RH abnormalities (Di Martino et al., 2011; Jou et al., 2010; Lazarev et al., 2009; Orekhova et al., 2009; Ozonoff & Miller, 1996; Siegal et al., 1996), this might imply that additional training would have led to greater benefits, particularly in the High AQ group. While this is clearly a topic for future research, it is still apparent from the present findings that even a single session of CPT is sufficient to increase global processing in a High AQ sample.

A final possible account involves the relative size of the attentional spotlight or window for our Low and High AQ groups. The attentional spotlight has been described
as moveable “beam” that can be expanded and narrowed to facilitate processing of visual stimuli (Eriksen & Yeh, 1985; Posner, 1990). Previous work has demonstrated that children with ASC show an impaired ability to widen the attentional spotlight relative to typically developing children (Mann & Walker, 2003) and, assuming our Low AQ group in Experiment 2 had generally broader attentional windows than our High AQ group, this could account for their relatively longer RTs for local-categorization, as their wider spotlight is more likely to be captured by the global information rather than local-level detail.

Importantly, the size of the attentional window can be altered. For example, a LH-damaged patient with right neglect were better at detecting right-sided targets presented on a small circle stimulus when their attentional window was broadened by including trials with larger circles (Hillis, Mordkoff, & Caramazza, 1999). CPT training may similarly broaden the size of the attentional window, suggesting an alternative account for CPT training benefits reported by Degutis and Van Vleet (2010). Rather than CPT increasing RH activation and consequently shifting attention leftward, CPT may have broadened the attentional spotlight resulting in more ‘leftward’ parts of landmark stimuli being attended. Applying a similar logic to the present study, CPT training may have broadened the attentional spotlight, making global-level information more accessible. This could explain why training increased global interference for local-categorization in our High AQ group, but not in our Low AQ group. This explanation is, of course, speculative at this point, but clearly warrants more detailed investigation in future work.

A separate analysis of CPT and CCT training effects, identical to the analytic procedure used by Van Vleet et al. (2010), indicated that only CPT training significantly shifted processing towards global aspects of the HFT. However, in combined analyses, neither the relevant three-way (Experiment 1) or four-way (Experiment 2) interaction involving training type were significant, suggesting both types of training yielded similar behavioral change. One likely explanation for this discrepancy is simply that our analyses lacked adequate statistical power to detect these higher-order interactions. Nevertheless, the similar patterns of change across tasks clearly visible in Figures 4.2 and 4.3 suggests that other factors may also be at work. In particular, the tonic and phasic attentional effects arising from CPT may also be generated by the CCT task, albeit in a weaker form, given the absence of CCT-related training effects. Importantly, this does not diminish the relevance of the present findings, which clearly show that behavioral training can alter global processing in individuals with high AQ.
However, it does suggest that more appropriate control tasks be used instead of CCT as low levels of attentional training effects induced by CCT may otherwise mask group differences between CPT and CCT training groups. Such similarities reduce the ability to detect CPT training effects and may explain why our higher-order interactions that included training type did not reach significance.

Due to the substantively similar pattern of results across studies that have compared ASC versus neurotypical individuals, and high versus low autistic trait individuals (for a meta-analysis \cite{cribb2016; see also: bayliss_kritikos2011; grinter_van_beek2009; grinter_maybery2009; rhodes2013; russell-smith2012; sutherland_crewther2010}, the results of this study can be interpreted as a preliminary indication that CPT may also increase global processing in clinically diagnosed individuals with ASC. These training effects could potentially benefit people with ASC by encouraging the use of global processing styles when they might otherwise employ a default local processing style. As an illustration of how such training might manifest itself in changes in task performance, consider the study of Rutherford and McIntosh (2007) who demonstrated that individuals with ASC show a greater tolerance for faces with exaggerated facial features which could be the result of depending upon strategies that use rule-based, piecemeal processing to identify shapes and infer emotions, rather than a holistic strategy that compares the face stimulus to a known gestalt or template. Applying the findings of our study to this context, we would hypothesize that if the ASC participants were administered a session of CPT before the face processing task, they would be more inclined to use a global strategy rather than a rule-based strategy, potentially reducing their tolerance for unrealistic emotional expressions. Naturally, the precise ability for CPT to influence the processing of face stimuli has yet to be examined, with demonstrations of the effectiveness of CPT currently limited to hierarchical Navon figures. The degree to which this behavioral task could influence perceptions of face stimuli should be explored.

This study provides the first evidence, to our knowledge, that local attentional biases can be modulated in individuals with high levels of autistic traits. In so doing, it suggests that CPT, or other techniques to enhance RH activation, such as transcranial direct current stimulation, might be useful in enhancing global processing and potentially related skills such as face recognition and emotion identification. Of course, the implications of these results for ASC are necessarily speculative at this point. Further research into the usefulness of CPT in the context of autism is needed.
References


CHAPTER FIVE

Modulating attentional biases of adults with autistic traits using transcranial direct current stimulation: a pilot study

Michael C W English, Emma S Kitching, Murray T Maybery and Troy A W Visser

While neurotypical individuals over-attend to the left-side of centrally-presented visual stimuli, this bias is reduced in individuals with autism/high levels of autistic traits. Because this difference is hypothesized to reflect relative reductions in right-hemisphere activation, it follows that increasing right-hemisphere activation should increase leftward bias. We administered transcranial direct current stimulation (tDCS) over the right posterior parietal cortex to individuals with low levels (n = 19) and high levels (n = 15) of autistic traits whilst completing a greyscales task. Anodal tDCS increased leftward bias for high-trait, but not low-trait, individuals, while cathodal tDCS had no effect. This outcome suggests that functional imbalances in hemispheric activation for attentional mechanisms in high-trait individuals can be restored following right-hemisphere stimulation.
Whilst neurotypical individuals tend to show pseudoneglect, an attentional bias towards stimulus features presented in the left hemifield (Jewell & McCourt, 2000) driven by the relatively greater lateralization of spatial attention to the right hemisphere (RH) (Siman-Tov et al., 2007), this attentional bias is reduced in individuals with autism spectrum conditions (ASC). Compared to controls, adults with ASC and infants with older ASC siblings show reduced eye-gaze to the left side of centrally-presented faces (Dundas, Best, Minshew, & Strauss, 2012; Dundas, Gastgeb, & Strauss, 2012), whilst adults show reduced leftward bias on face-identity matching tasks (Ashwin, Wheelwright, & Baron-Cohen, 2005). Similar patterns are also found for neurotypical individuals with high levels of autistic-like traits (High ALT) viewing non-face stimuli (Chapter 2 & 3 of the present thesis; henceforth English, Maybery, & Visser, 2015, 2017).

Another aspect of attention linked to RH regions is global processing; the ability to integrate multiple independent stimuli into a coherent and meaningful whole (Hübner & Studer, 2009; Malinowski, Hübner, Keil, & Gruber, 2002; Weissman & Woldorff, 2005; Yamaguchi, Yamagata, & Kobayashi, 2000). Here too, individuals with ASC/High ALT show a reduction in global processing relative to neurotypical peers (for meta-analyses, see Cribb, Olaithé, Di Lorenzo, Dunlop, & Maybery, 2016; Van der Hallen, Evers, Brewaëys, Van den Noortgate, & Wagemans, 2015). In turn, this reduced global processing has been linked with poorer face identification and emotional recognition (Behrmann, Thomas, & Humphreys, 2006; Gross, 2005) – key elements of social processing.

It is possible that reductions in both pseudoneglect and global processing are the result of a functional imbalance in the activation of the two hemispheres for spatial attention in individuals with ASC/High ALT. If that were the case, non-invasive transcranial direct current stimulation (tDCS) might be effective in shifting this imbalance and modulating associated attention-related task performance. TDCS has been previously used to elicit shifts in spatial attention by stimulating or disrupting posterior parietal cortex (PPC) activation in neurotypical individuals (Loftus & Nicholls, 2012; Roy, Sparing, Fink, & Hesse, 2015; Sparing et al., 2009) and to improve social functioning outcomes for individuals with ASC via disruption of the left dorsolateral prefrontal cortex (D’Urso et al., 2014, 2015). However, to our knowledge, no study has attempted to invoke attentional shifts using tDCS in individuals with either ASC or High ALT.
The present study aims to provide preliminary examination of the attentional changes induced via anodal and cathodal tDCS of the right PPC of neurotypical adults with Low and High ALT. Attentional changes as a result of tDCS were assessed by measuring performance on the greyscales task (Nicholls, Bradshaw, & Mattingley, 1999), which has been shown to be sensitive to differences in attentional bias between Low and High ALT groups (English et al., 2015, 2017).

Method

Participants

Thirty-eight right-handed undergraduate students from the University of Western Australia participated in the study in exchange for partial course credit.

Materials

Questionnaires

ALT levels were assessed using the Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), a 50-item self-report questionnaire, scored using Austin's (2005) 1-4 method. Handedness was assessed using the ten-item Edinburgh Handedness Inventory (Oldfield, 1971).

Greyscales Task

The task was adapted from English et al. (2015). Stimuli were generated using Presentation software (Version 17.0, Neurobehavioral Systems) and presented on a 24" BenQ XL2420T monitor. Participants were seated approximately 50cm from the display. Trials consisted of a central fixation cross presented for 1500ms, followed by two horizontal bars presented above and below the display's centre. From the left, one bar was shaded white-to-black, with the number of black pixels increasing evenly across the stimulus. The other bar was shaded similarly but in the reverse direction (Figure 5.1). Finally, one bar was ‘darker, achieved by randomly replacing 100 white pixels with black pixels evenly across the bar, and similarly replacing 100 black pixels with white pixels across the other bar. The top/bottom positions of the left-to-right shaded bar and the overall darker bar were varied randomly but counterbalanced across trials. Participants were instructed to select the bar they perceived was ‘darker’ overall by pressing the T ("top") or B ("bottom") keys. Participants had 5s to make their response – if no response was recorded, the trial was repeated after the remaining trials.
Transcranial Direct Current Stimulation (tDCS)

Stimulation was applied to the right PPC using a battery-driven stimulator (Dupel Iontophoresis System, MN) via a pair of 6x4 cm electrodes placed on the scalp in saline-moistened sponge pouches. Electrode configuration followed that used in prior work (Loftus & Nicholls, 2012; Roy et al., 2015; Sparing et al., 2009). During anodal stimulation, the reference was placed at the Cz position according to the International 10-20 System (Klem, Lüders, Jasper, & Elger, 1999), and the active electrode at P4. This configuration was reversed for cathodal stimulation. For anodal and cathodal stimulation, the current was gradually ramped up to 2mA over 30s and maintained at this level for the duration of the session. Mean stimulation duration was 9.76 min (SD = 2.06) and a repeated measures analysis of variance (ANOVA) showed that durations did not differ across stimulation conditions or ALT groups (all ps > 0.55, all $\eta^2_p$ < 0.02).

Procedure

Participants completed the experiment over two days separated by a minimum 24-hour period (see Figure 5.2 for a diagram of the experimental flow). On each day, participants completed two 168-trial sessions of the greyscales task. There were four session types. In the initial practice session, participants completed the task without wearing the tDCS apparatus. In the anodal and cathodal sessions, the respective stimulation was applied during the task. In the sham (placebo) condition, the current was ramped up to 2mA, but immediately ramped down again over 30s. This was intended to create a physical experience like anodal and cathodal stimulation with minimal or no effect on neural excitability (Loftus & Nicholls, 2012; Sparing et al., 2009). The administration order of the anodal and cathodal conditions was
counterbalanced across participants and always followed the practice/sham sessions to avoid carry-over stimulation effects between sessions.

Figure 5.2. Order of administration of the tDCS conditions, with half of the sample receiving the first order and half the second.

Results

Low- and High-ALT groups were created using a median split of AQ scores (median = 107) following previous methodology (English et al., 2015). Accuracy was calculated as the percentage of trials on which participants selected the darker stimulus. Pseudoneglect was calculated as the percentage of trials on which participants selected the bar with most black pixels oriented towards the left side of the screen.

Four participants (1 Low ALT, 3 High ALT) data were omitted because their pseudoneglect scores across the anodal, cathodal and sham sessions were identified as multivariate outliers (Mahalanobis Distance: $\chi^2 > 7.82, p < 0.05$). The remaining participants descriptive statistics are presented in Table 5.1. An independent-samples t-test confirmed that AQ scores differed between Low- and High-ALT groups, $t(32) = 8.20, p < 0.001, d = 2.90$. 

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Table 5.1. Descriptive statistics for the Low and High ALT groups (standard deviations presented in parentheses)

<table>
<thead>
<tr>
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<th>Low ALT (n=18)</th>
<th>High ALT (n=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>8 male, 10 female</td>
<td>10 male, 6 female</td>
</tr>
<tr>
<td>Mean age (years)</td>
<td>21.28 (1.23)</td>
<td>21.19 (2.00)</td>
</tr>
<tr>
<td>Mean AQ</td>
<td>95.67 (9.75)</td>
<td>120.63 (7.72)</td>
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A one-sample t-test verified that mean task accuracy (M = 55.25%, SD = 5.87%) was significantly greater than chance levels (50%), t(31) = 5.21, p < 0.001, d = 1.68. We also verified that any changes in pseudoneglect were not attributable to variations in accuracy by submitting mean accuracy scores to a 2 (ALT Group; Low or High) x 3 (Stimulation Type; anodal, sham and cathodal) repeated-measures ANOVA. No main effects or interactions were found (all ps > 0.23, all $\eta^2$s < 0.04).

To test our main research question, mean pseudoneglect scores were submitted to a 2 (ALT Group) x 3 (Stimulation Type) ANOVA (mean scores illustrated in Figure 5.3). This analysis revealed no main effect of AQ Group, $p = 0.36$, $\eta^2_p = 0.03$, but a main effect of Stimulation Type, $F(2,34) = 14.06$, $p < 0.001$, $\eta^2_p = 0.31$, and, importantly, an ALT Group x Stimulation Type interaction, $F(2,34) = 5.83$, $p < 0.01$, $\eta^2_p = 0.15$. To determine the source of the interaction, we used paired-samples t-tests (Bonferroni corrected) to compare pseudoneglect scores in the sham condition relative to the anodal and cathodal conditions separately for each ALT group. The High ALT group showed a significant difference between sham and anodal stimulation conditions, t(15) = 4.09, $p < 0.001$, $d = 0.65$, and a near-significant difference between sham and cathodal stimulation conditions, $p = 0.06$, $d = 0.28$. For the Low ALT group, sham stimulation did not differ from either anodal or cathodal stimulation (both $ps > 0.35$, both $ds < 0.07$).

1 It could be argued that an absence of a main effect of AQ group here can be considered a failure to replicate the findings presented in Chapter 2 and 3. However, it is more likely that the participant sample in this study was merely not large enough to obtain a significant comparison. This is not problematic, as the purpose of the current study is to address whether tDCS differentially influences spatial biases between AQ groups – a question that can be answered without the larger sample sizes recruited in the previous studies.
Figure 5.3. Pseudoneglect levels associated with each of the three types of stimulation (error bars represent one standard error of the mean). The dashed line highlights the level at which no pseudoneglect is present. *** $p < 0.001$.

Discussion

Following behavioral evidence that reduced levels of pseudoneglect and global processing in individuals with ASC/High ALT potentially reflect relatively lower activation of the RH (English et al., 2015, 2017), the present study examined whether tDCS applied over the right PPC could alter attentional biases in these individuals. Consistent with this hypothesis, anodal tDCS significantly increased pseudoneglect in our High ALT group relative to sham stimulation, while not yielding a significant increase in pseudoneglect in our Low ALT group. Such a pattern of results would be expected as the result of baseline pre-stimulation differences in RH activation between the two groups (English et al., 2015; Loftus & Nicholls, 2012). That is, the increased cortical excitability arising from anodal tDCS would more effectively increase RH activation in our High ALT group with lower pre-stimulation baseline, than in the Low ALT group, with relatively higher pre-stimulation RH activity. In turn, this would yield
greater increases in levels of pseudoneglect in the High ALT group than in the Low ALT group. However, this account is somewhat speculative given that a baseline group difference in hemispheric activation was not observed in the present study and further investigation would be needed to confirm this interpretation.

Our findings also offer a fresh perspective on the failure of Loftus and Nicholls (2012) to observe an effect of right-PPC anodal stimulation on pseudoneglect in an ALT-unselected neurotypical sample. While the authors proposed that this outcome reflected generally high levels of right PPC pre-stimulation activation, our results suggest that this explanation may not adequately account for individual differences arising from variations in levels of autistic traits. Put differently, it is likely that testing an unselected neurotypical sample which, collectively, likely had relatively high levels of RH activation, masked effects of anodal tDCS – effects which may be more readily apparent in a subset of individuals with relatively higher levels of autistic traits (and thus lower RH baseline activation).

Cathodal tDCS failed to produce any significant reductions in pseudoneglect for either ALT group. One plausible explanation is that factors other than baseline activation more strongly modulate the impact of cathodal stimulation. Indeed, effects of cathodal stimulation have not been observed in numerous studies (for a review, see Jacobson, Koslowsky, & Lavidor, 2012), and a multitude of factors, including stimulation duration, location and intensity, as well as task complexity, seem to contribute to situations where anodal and cathodal stimulation do not lead to systematic changes (Vallar & Bolognini, 2011). Given that the effects of cathodal stimulation are generally less robust than those arising from anodal stimulation, we suggest that further research is required to better understand the possible implications of the lack of cathodal stimulation effects on pseudoneglect.

In summary, this study is the first to our knowledge to show that atypical attentional biases in individuals with High ALT may be modulated using non-invasive cortical stimulation. If pseudoneglect can be shifted (at least, temporarily), what other aspects of attention could be similarly altered regarding autism? Spatial processes that have a relatively greater reliance on regions in the RH, such as global processing, potentially stand to benefit from techniques such as tDCS. For example, tDCS could assist with increasing otherwise low levels of RH activation that may be contributing to slowed global processing in autism (Van der Hallen et al., 2015), which is itself linked with less accurate/efficient processing of socially relevant information such as faces (Behrmann, Avidan, et al., 2006; Gross, 2005). Furthermore, determining the extent to
which attentional modulations in individuals with ASC/High ALT can be made to persist over time will help establish the scope of changes that could arise from techniques to stimulate RH activity. A limitation of the present study that could be addressed in future work is the relatively small sample size observed, and a replication with a larger sample would assist in confirming the present findings. Finally, it is also critical to confirm the present findings using a sample with ASC as while individuals with High ALT are susceptible to attentional modulations following tDCS, this may not be true of individuals with ASC.

References


CHAPTER SIX

General Discussion

Central Aims of this Thesis

While early conceptualizations of autism focused on the role of the child’s social environment in the disorder, more contemporary theories have incorporated research findings from studies of cognitive and perceptual mechanisms including spatial attention. The weak central coherence model, for example, suggests that many autistic behaviours stem from a failure to integrate independent pieces of information into a coherent whole, something that is demonstrated by autistic individual’s superior attention to detail on spatial tasks such as the Embedded Figures Test (EFT). With the development of psychometric tools, such as the Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), it is now known that atypical spatial attention is not strictly limited to those individuals diagnosed with autism spectrum conditions (ASC). Similar atypical attention effects are often seen in neurotypical individuals with high levels of autistic traits (High AQ) compared to individuals with low levels of autistic traits (Low AQ). That said, many important questions remain about the mechanisms that underlie atypical distribution of spatial attention seen in both ASC and High AQ individuals.

The objective of the present thesis was to investigate whether relatively reduced right hemisphere activation contributes to atypical spatial attention seen in individuals with High AQ. This objective was divided into two separate, but related, research aims. The first aim was to produce novel behavioural evidence that reduced RH activation mediating spatial attention is linked to increasing levels of autistic-like traits. This was achieved by comparing the spatial biases of Low and High AQ
participants on several attentional measures, such as the greyscales and landmark tasks. The second aim extended the first by examining whether aspects of spatial attention considered atypical in ASC and High AQ, such as poor global processing, may be overcome in High AQ individuals by using techniques that increase RH activation. In what follows, findings and implications drawn from two studies investigating the first aim are summarized and discussed, before moving on to a similar treatment of the two studies that investigated the second aim.

Part 1: New Evidence for Reduced Right Hemisphere Activation for adults with autistic-like traits

Individuals with autistic-like traits show reduced lateralization on a greyscales task

In the first experimental chapter of this thesis, Chapter Two, attentional biases on the greyscales task (Nicholls, Bradshaw, & Mattingley, 1999) were observed for neurotypical adults with low or high levels of autistic traits, as measured using the AQ (Baron-Cohen et al., 2001). Tasks that index attentional lateralization, such as greyscales, landmark and line bisection tasks, are useful indicators of underlying asymmetries in hemispheric activation, and are often used to observe left hemispatial neglect following right-sided cortical lesions (Heilman, Watson, & Valenstein, 1997).

Previous work has found a reduced leftward bias by ASC individuals when viewing face stimuli (Ashwin, Wheelwright, & Baron-Cohen, 2005; Dundas, Best, Minshew, & Strauss, 2012; Guillon et al., 2014), but it was not clear if this attention-related behaviour would generalize to other types of visual stimuli or to neurotypical individuals with High AQ. However, given that both ASC and High AQ participants show superior performance, relative to healthy controls and Low AQ participants respectively, for attentional tasks that do not use face stimuli, such as the EFT (Cribb, Olaithe, Di Lorenzo, Dunlop, & Maybery, 2016; Muth, Hönekopp, & Falter, 2014), it was predicted that High AQ participants would also show a reduced leftward attentional bias, or pseudoneglect (Bowers & Heilman, 1980), on the greyscales task.

To maximize the likelihood of detecting an effect of AQ scores on pseudoneglect, a relatively large number of participants (n = 277) were recruited across the entire distribution of possible scores. When analysing the sample as two groups based on whether participant’s AQ scores were above or below the sample median (Low vs High AQ), pseudoneglect was found to be significantly lower in the
High AQ group compared to the Low AQ group, though still above chance levels (indicating that pseudoneglect was still present in the High AQ group). Furthermore, while overall AQ scores did not directly correlate with levels of pseudoneglect, the social skills factor score of the AQ (Russell-Smith, Maybery, & Bayliss, 2011) was associated with pseudoneglect levels, with increased social difficulty linked to reduced pseudoneglect.

Beyond greyscales: reduced pseudoneglect for other tasks

The experiment outlined in Chapter Three extended the findings presented in Chapter Two. The goal here was to replicate the initial results obtained using the greyscales task and to determine whether differences in attentional bias between Low and High AQ individuals could also be observed on a landmark task and a mental number line task. As the findings presented in Chapter Two were the first to show differences in attentional lateralization as a function of autistic traits, a replication was prudent. The inclusion of the landmark task was designed to test if some unique aspect of the greyscales stimuli was driving the reduced pseudoneglect seen for High AQ participants in Chapter Two, or if reduced pseudoneglect could be observed across variations in visual stimuli. The inclusion of a mental number line task, which does not require judgements about visual stimuli, allowed us to examine whether Low and High AQ individuals also showed different attentional biases for mental representations of space.

The findings reported in Chapter Two were replicated, with significantly reduced levels of pseudoneglect present in the High AQ group for both the greyscales and landmark task in this study. Furthermore, unlike the findings in Chapter Two, pseudoneglect was absent in the High AQ group in both of these tasks. However, analyses of pseudoneglect on the mental number line task differed to all the findings presented thus far, with significant and statistically indistinguishable levels of pseudoneglect observed for the Low and High AQ groups.

Part 1: Discussion

Given the evidence that global processing is impaired in ASC (for review, see Van der Hallen, Evers, Brewaeps, Van den Noortgate, & Wagemans, 2015), and that less-active RH regions responsible for global processing may, at least partially, contribute to this impairment (for review, see Happé & Frith, 2006), it is somewhat surprising that few studies have sought converging behavioural evidence for RH-based spatial attention impairments in ASC. While several studies do demonstrate that ASC
individuals (Dundas, Best, et al., 2012; Guillou et al., 2014), and infants with ASC siblings (Dundas, Gastgeb, & Strauss, 2012), show a reduced leftward bias for viewing faces indicative of reduced RH lateralization for spatial attention, these findings have not been replicated for non-face stimuli. The finding reported in Chapter Two is therefore the first, to my knowledge, to show that attentional biases are atypical in a group of High AQ individuals viewing non-face stimuli. Confirming this finding, the study presented in Chapter Three replicated this effect and demonstrated that a similar pattern exists for the landmark task. Should similar patterns also be present in a clinical ASC sample, reduced (or absence of) pseudoneglect could be interpreted to be a potentially new phenotypic expression of ASC that is indicative of reduced RH activation for spatial attention. The importance of extending the present findings with neurotypical individuals to ASC groups is discussed in greater detail below.

It should be noted that one study offers evidence that potentially conflicts with, or at least qualifies, the present findings. Rinehart, Bradshaw, Brereton and Tonge (2002) reported that spatial biases measured using the greyscales task in children with ASC were no different to those seen in typically developing (TD) children. On the face of it, this result would seem to indicate a disparity between Low/High AQ and TD/ASC comparisons for pseudoneglect. However, the interpretability of the results is obfuscated by the fact that the TD control group in Rinehart et al. (2002) failed to show any pseudoneglect, which conflicts with other demonstrations of pseudoneglect in children (Dellatolas, Coutin, & De Agostini, 1996), and evidence that pseudoneglect is more prominent in younger children and decreases with age (Jewell & McCourt, 2000). It is also possible that the present significant findings stem from the use of a larger sample, additional trials, and the ability to screen participant engagement based on task accuracy (Rinehart et al.’s stimuli were equiluminant and therefore their task did not have ‘correct’ or ‘incorrect’ trials). In the end, a study that combines the present experimental methodology with Rinehart et al.’s ASC and TD comparison groups would help provide definitive answers as to the reasons for the disparate findings.

The results reported in Chapter Two regarding the relationship between levels of pseudoneglect and scores on individual factors within the AQ were unexpected. Specifically, the social skills component score and greyscales pseudoneglect index were negatively correlated (i.e., greater social difficulties were linked to reduced pseudoneglect), whereas no such relationship was apparent between the pseudoneglect index and the details/patterns component score of the AQ. A similar result was reported by Russell-Smith and colleagues (2012) who found that superior
EFT performance correlated positively with scores for the social skills factor of the AQ (i.e. faster EFT reaction times (RTs) were associated with greater social difficulty), but not with scores for the details/patterns factor. It is interesting that, in both cases, attentional performance was more closely associated with the social ability factor of the AQ, which suggests that the mechanisms responsible for reduced pseudoneglect and faster EFT RTs in High AQ individuals potentially have links to social functioning. However, it should also be noted that this relationship was somewhat weak in the results presented in Chapter Two, and it is possible that the association with the social skills factor is in part a result of the factor also being the largest (and therefore best reflection of overall AQ) out of the three.

That being said, previous research has noted that the individual subfactors comprising the AQ are relatively independent, as scores for factors relating to social ability and factors encompassing rigid interests, details and patterns are not observed to correlate (Dworzynski, Happé, Bolton, & Ronald, 2009; Russell-Smith et al., 2011). The absence of a close relationship between these factors is consistent with how pseudoneglect and EFT performance (Russell-Smith et al., 2012) correlate with the one factor, but not the other. However, further inspection of the AQ factor scores for the study reported in Chapter Two reveals that the social skills and details/patterns factor scores were, in fact, modestly correlated (Pearson correlation: $r = 0.18$, $p < 0.01$). Thus, even in populations for which the two factors do correlate, it is the social skills scores, and not the details/patterns scores, that are associated with perceptual performance.

Assuming the relationship between pseudoneglect and social ability is not coincidental, why are the two associated? One possibility is that both reduced pseudoneglect and social difficulty are partly driven by relatively reduced RH activation for spatial attention. Pseudoneglect itself likely manifests due to the RH lateralization of spatial attention in neurotypical individuals (Fierro et al., 2000; Fink, Marshall, Weiss, Toni, & Zilles, 2002; Foxe, McCourt, & Javitt, 2003; Harris & Miniussi, 2003; Siman-Tov et al., 2007; Vingiano, 1991). The RH is also linked to central coherence (Evans, Shedden, Hevenor, & Hahn, 2000; Flevaris, Bentin, & Robertson, 2010; Hübner & Studer, 2009; Lux et al., 2004; Malinowski, Hübner, Keil, & Gruber, 2002; Volberg & Hübner, 2004; Weissman & Woldorff, 2005; Yamaguchi, Yamagata, & Kobayashi, 2000) and face processing ability (Clark et al., 1996; Haxby et al., 1994, 1999; Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997; Rossion, Schiltz, & Crommelinck, 2003; Sergent, Ohta, & Macdonald, 1992), which, in turn, contributes towards communication ability and overall social functioning.
Further investigation is required to confirm that reduced RH activation underlies levels of pseudoneglect expression, central coherence, and social ability as measured using the AQ.

The absence of group differences for the mental number line task suggests that spatially-organized mental representations are not influenced by higher levels of autistic traits like their perceptually derived counterparts. This dissociation resembles the results of previous studies of patients with RH damage that showed dissociations between effects on perceptual and representational biases (Doricchi, Guariglia, Gasparini, & Tomaiuolo, 2005; Loetscher & Brugger, 2009; Loetscher, Nicholls, Towse, Bradshaw, & Brugger, 2010; Pia et al., 2012; Rossetti et al., 2011; Storer & Demeyere, 2014; van Dijck, Gevers, Lafosse, & Fias, 2012). This would also suggest that the mechanism that leads to reduced pseudoneglect with increasing autistic traits is likely linked to the sensory system, given that no differences are present in the absence of needing to visually inspect stimuli.

A key question arising from the findings reported in Chapters 2 and 3 concerns the nature of cortical changes underlying performance differences between High and Low AQ individuals. Previous work has shown that changes in relative activation of the left and right posterior parietal cortex (PPC) appear to induce systematic attentional shifts on tasks that index the lateralization of spatial attention. In neurotypical individuals, using anodal tDCS to increase right PPC activation is associated with a leftward shift in attention (Roy, Sparing, Fink, & Hesse, 2015; Sparing et al., 2009). Similarly, using TMS to disrupt right PPC activation or cathodal tDCS to increase left PPC activation leads to a rightward shift in the perceived midpoint of horizontal lines (Fierro, Brighina, Piazza, Oliveri, & Bisiach, 2001; Loftus & Nicholls, 2012). TMS-related changes in hemispheric activation have been confirmed with fMRI, as TMS over the right angular gyrus/intra-parietal sulcus in neurotypical individuals has been found to abolish pseudoneglect and shift the relative balance of parietal activity from right to left (Petitet, Noonan, Bridge, O’Reilly, & O’Shea, 2015). It can be inferred from the results of these studies, that a strong candidate for the neural substrate for reduced pseudoneglect in the present High AQ groups is the right PPC.

Notably, changes in PPC activation have also been strongly linked with attentional shifts for mental representations of space – for example, disrupting right PPC activation of neurotypical participants using TMS leads to rightward shifts on a number line bisection task (Göbel, Calabria, Farnè, & Rossetti, 2006; Göbel, Walsh, & Rushworth, 2001). Nevertheless, significant differences between Low and High AQ
groups on the mental number line task in Chapter Three were not observed. This may suggest that areas other than the PPC can be linked to representational pseudoneglect in High AQ participants. One potential candidate could be right prefrontal working memory structures, which are linked to maintaining the mental number line (Doricchi et al., 2005). These areas do not show activity changes during perceptual-based lateralization tasks, which are instead strongly associated with activation of the striate and extrastriate visual cortex and parietal lobes (Doricchi & Angelelli, 1999; Fink et al., 2000). It is possible that functioning in these memory-related regions remains intact for individuals with higher levels of autistic-like traits and that this compensates for reduced right PPC activation when accessing mental representations of space. Further, given these prefrontal areas are not readily involved in lateralization judgements of visual stimuli, the absence of compensatory mechanisms in the presence of visual cortex and parietal lobe deficits may account for the disparate results across perceptual and representational measures of space.

Rather than a deficit in a single brain region, it is also possible that a neuronal pathway abnormality may underlie reduced pseudoneglect for High AQ individuals. Visual processing beyond the primary visual cortex is largely divided into two separate pathways. The ventral stream/parvocellular pathway is associated with the processing of higher spatial frequencies and stimulus recognition. The dorsal stream/magnocellular pathway, is associated with processing lower spatial frequencies, motion and spatial relations between objects (Culham, He, Dukelow, & Verstraten, 2001; Felleman & Van Essen, 1991; Livingstone & Hubel, 1988; Merigan, Byrne, & Maunsell, 1991; Merigan & Maunsell, 1993; Young, 1992). Spencer et al. (2000) and Milne et al. (2002) suggested that deficits may exist in the dorsal stream for ASC individuals after finding that individuals with ASC have atypically large thresholds for the detection of coherent global motion. Consistent with this possibility, global coherence thresholds are inversely related to EFT performance for children with ASC, indicating a link between ASC and reduced involvement of global processing for both static and moving global arrangements (Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005), with identical findings reported when comparing neurotypical individuals with High and Low AQ (Grinter et al., 2009). Critically, the dorsal stream has greater input into parietal regions than the ventral stream (Milner & Goodale, 2006) and there may be weakness within the dorsal stream that leads to the right PPC. In short, this account suggests that reduced pseudoneglect in High AQ individuals is potentially due to
deficits existing in the dorsal stream/magnocellular pathway that connects to the right PPC, rather than deficits existing in the right PPC itself.

While reduced RH activation may result in reduced pseudoneglect on tasks that index lateralization, and greater attentional preferences to the local-level of visual stimuli, it remains unknown the extent to which these two aspects of attention are directly associated. Potentially, global processing styles dominate when observing the visual stimuli presented in Chapter Two and Three (Çiçek, Deouell, & Knight, 2009; Fink et al., 2002; B. H. Lee et al., 2004; Nicholls, Mattingley, & Bradshaw, 2005), and the relatively greater RH activation that results from engaging in global processing in turn drives greater levels of pseudoneglect. Consequently, High AQ participants may be less inclined to engage in global processing when viewing these stimuli, resulting in reduced hemispheric asymmetry in activation levels and reduced pseudoneglect. Evidence in support of this notion comes from a study conducted by Nicholls, Mattingley and Bradshaw (2005), who reported that neurotypical participant’s pseudoneglect for greyscales stimuli is reduced when the use of local processing strategies is facilitated by segmented the stimuli into halves or quarters.

With this finding in mind, one avenue for future research would be to determine how pseudoneglect in Low and High AQ participants is altered due to segmentation – if only the Low AQ group sees reductions in pseudoneglect, an absence of change in the High AQ group could be interpreted as evidence suggesting that they are already using a more locally-oriented processing style, which in turn alters hemispheric asymmetries in activation that potentially accounts for the reduced pseudoneglect in this group. This line of reasoning also offers another possible account for why differences in pseudoneglect between AQ groups were not present in the mental number line task: an absence of a visual stimulus to inspect meant that global/local processing preferences were not engaged.

Future studies should also examine whether a common neural mechanism underlies pseudoneglect and the expression of global/local biases on measures like the EFT. Evidence from neuroimaging studies suggests that the ability to perceive target shapes in EFT stimuli (disembedding) is linked to LH functioning. In one study, EFT completion was associated with greater left inferior and left superior parietal cortex activation relative to completing a visual search control task for neurotypical participants (Manjaly et al., 2003). Another study revealed that ASC children completing the EFT also showed left superior parietal activation, relative to TD children who showed bilateral activation of the same region (P. S. Lee et al., 2007).
Finally, in neurotypical individuals, superior EFT disembedding is associated with greater volumes of grey matter in the left inferior parietal lobule (Hao et al., 2013). Given this evidence, together with the findings that suggest that relative left and right PPC activation influences pseudoneglect, I expect that reduced pseudoneglect arising from relatively reduced RH activation, would be associated with superior EFT disembedding. To my knowledge, only one study has examined the two constructs together, confirming that reduced pseudoneglect is associated with superior EFT disembedding (Glicksohn & Kinberg, 2009). However, further work is required to establish the strength of this relationship and the contribution of autistic traits to it. Research is presently being conducted in the laboratory to investigate this extension of the work reported in this thesis.

**Part 2: Increased Right Hemisphere Activation**

**‘Corrects’ Attention in Adults with Autistic-Like Traits**

Chapters Four and Five were a logical progression of the research reported in the preceding two chapters, shifting from the observation of spatial attention differences linked to reduced RH activation in High AQ individuals, to directly testing whether increasing RH activation can alter the distribution of spatial attention in these individuals. The experimental designs used in Chapters Four and Five were selected on the basis that, in unselected neurotypical participants, they had been shown to alter aspects of spatial attention considered atypical in ASC and High AQ. These aspects included global processing ability (Cribb et al., 2016; Van der Hallen et al., 2015) and the distribution of spatial attention, as demonstrated in Chapters Two and Three, and other studies (Ashwin et al., 2005; Dundas, Best, et al., 2012).

**Improving global processing using a RH-activating continuous performance task**

In Chapter Four, I tested whether an attentional training task could alter biases towards the global and local levels of hierarchical Navon figures, in different ways for groups selected to differ in levels of autistic-like traits. Previous work has found that engaging in a continuous performance task can result in leftward spatial shifts on a landmark task (Degutis & Van Vleet, 2010) and increases in attention directed towards the global level of Navon figures (Degutis & Van Vleet, 2010) for RH-damaged patients with left neglect. Critically, both of these attentional changes can be explained by relative increases in RH activation arising from training on the CPT. Given that the present thesis presents additional evidence for reduced RH activation for spatial
attention in High AQ individuals (Chapters Two and Three), and global processing is closely linked with RH activation (for a review see Ivry and Robertson, 1998), it seemed appropriate to investigate whether CPT could increase attention directed towards the global-level of visual stimuli for neurotypical individuals with High AQ.

To this end, two experiments were carried out. The first experiment was designed to confirm the findings reported Van Vleet et al. (2011) with an unselected sample, while the second was designed to test whether CPT training influenced global processing in neurotypical participants with high levels of autistic like traits. The results of the replication study showed the same key findings as Van Vleet et al. (2011) – after training, participants were better at ignoring the local level of Navon figures when directed to categorize the global level, and worse at ignoring the global-level when directed to categorize the local-level. In the second experiment, which included neurotypical individuals with Low or High AQ scores, an interesting dissociation was found between the two AQ groups. Following CPT training, Low AQ individuals were better able to ignore local-level distractors during global categorization, while interference from global distractors during local categorization was unchanged. In stark contrast, High AQ participants were less able to ignore global-level distractors during local categorization, but saw no changes in their attention to local-level distractors during global categorization, following the CPT training. Also of significance, the present findings did depart from Van Vleet et al. (2011) in one key respect as training effects in both experiments persisted for a longer duration.

Increasing pseudoneglect using cortical stimulation

In Chapter Five, the final study of this thesis, the activation level of the right PPC in High and Low AQ individuals was modulated using tDCS and the resulting changes in the distribution of spatial attention observed using the greyscales task. The greyscales task was chosen as the measure for observing tDCS-related effects on attention because it is simple in design (all trials contributing to a single pseudoneglect index) and showed reliable differences between Low and High AQ participants in earlier studies. In contrast, the Navon figure categorization task described in Chapter Three is more complex (four conditions required to index the two forms of interference) and it did not provide reliable baseline differences between samples of Low and High AQ individuals.

The study in Chapter Five was motivated by previous work demonstrating that tDCS and TMS are effective at shifting attention towards the left or right-side of visual
space depending on whether stimulation excites or disrupts activation of the left or right PPC (Fierro et al., 2000, 2001; Loftus & Nicholls, 2012; Petitet et al., 2015; Roy et al., 2015; Sparing et al., 2009). In particular, Sparing et al. (2009) showed that excitatory, anodal tDCS over the RH was effective at reducing left hemispatial neglect symptoms of RH-damaged patients, shifting attention leftward. With these results in mind, it seemed reasonable to hypothesize that evidence for atypical lateralization for spatial attention seen in High AQ participants in Chapters Two and Three might be altered using tDCS applied over the right PPC.

Consistent with this possibility, anodal tDCS applied over the right PPC led to significantly greater levels of pseudoneglect for a High AQ group relative to a sham (control) stimulation condition. In contrast, no changes in pseudoneglect were observed in a Low AQ group. However, cathodal tDCS was not effective at producing systematic changes for either the High or Low AQ group, suggesting only excitation of the RH is able to alter spatial bias in High AQ individuals.

Part 2: Discussion

While substantial research has investigated the extent to which attention in ASC deviates from neurotypical profiles, to my knowledge, there are no studies that have attempted to overcome any of these deviations using methods that increase RH activation. This is somewhat surprising, given that prominent theories of autism, like the weak central coherence account (Frith, 1989), have posited a central role for attentional deficits that are linked to reduced RH activation. It is timely then that the results presented in Chapters Four and Five essentially provide the first indications that attentional patterns associated with ASC are not necessarily fixed and, at least for neurotypical individuals with High AQ, may be modulated with techniques that increase RH activation.

In both experiments in Chapter Four, CPT-related training effects were more enduring than those recorded by the original authors (Van Vleet et al., 2011). In comparing results of these studies, it was noted that reaction times during the CPT tended to be faster in the present study, but accuracy worse, indicative of a speed-accuracy trade-off. This pattern suggests that CPT-related attentional changes may be chiefly driven by participants making speeded responses, rather than correctly inhibiting responses per se. This notion is further supported by the fact that participants who completed the categorization control task (CCT) were not required to make speeded responses and did not show changes in global processing. Of course, CCT
also differed from CPT in that participants were required to respond to all stimuli, rather than inhibit certain stimuli classes, as was the case for CPT. Consequently, it is unknown to what extent the attentional mechanisms responsible for making speeded responses and those mechanisms responsible for correct response inhibition underlie attentional shifts towards the global level of Navon figures. Subsequent studies using this training paradigm may want to consider using variations of the current CCT to determine the extent to which speeded responses or correct inhibition make contributions towards CPT-related training effects. This could be achieved by altering CCT, which requires participants to make non-speeded categorizations of two stimulus classes (upright vs inverted images) each with 50% presentation rates, to a design where participants make speeded categorizations. With this change, it could be determined whether speeded-CCT induces attentional changes similar to CPT. Such a finding would indicate that attentional mechanisms responsible for speeded responses, rather than response inhibition, are associated with attentional shifts in global/local biases.

The present findings that individual differences in AQ scores lead to varying CPT-related attentional changes, has implications for the interpretation of Van Vleet et al.’s (2011) results. While their findings seemingly suggest that all neurotypical individuals show alterations on globally-directed and locally-directed variants of the Navon figure task as a result of CPT, the present study does not support this claim. Instead, it is likely that training effects varied with AQ levels, but that these variations were unobservable since AQ levels were not assessed. This notion is supported by the fact that training effects seen in Experiment 2, when collapsed across AQ groups, appear identical to those reported in Experiment 1 and in Van Vleet et al. (2011). This has important implications for future studies wishing to use this training paradigm, as such individual differences appear to have the capacity to significantly influence attentional training outcomes.

Alternatively, the differences between AQ groups may have in part arisen due to differences in baseline levels of task performance. Specifically, relatively higher baseline levels of global interference for local categorization seen in Low AQ individuals would have made it difficult for further increases in global interference to be detected post-CPT training (i.e. ceiling effects). Similarly, for the High AQ group, lower baseline levels of local interference for global categorization would have made it difficult for further reductions in local interference to be detected post-CPT training (i.e. floor effects). These differences in baseline levels that were present in the CPT
condition may not be reliable as the AQ groups who received the control training task were comparable in terms of pre-CPT performance. It is unfortunate that baseline levels were not well-matched for the High and Low AQ groups across the CPT and control training conditions. This issue could be addressed in subsequent studies by having participants complete both types of training, thus controlling for individual differences.

A further possibility is that additional training would have increased effect sizes, perhaps, enhancing changes in task interference that did not reach conventional levels of significance in Experiment 2. The present design followed the methodology outlined in Van Vleet et al. (2011) and administered a single 16-minute session of CPT, which was sufficient to produce measurable changes in attention in a neurotypical sample. By comparison, in Degutis and Van Vleet’s (2010) study with RH-damaged neglect patients, three 12-minute sessions were administered each day over nine consecutive days. Given the possibility that individuals with ASC may also have reduced RH activation for spatial attention, a longer training period may have been required to produce the full-breadth of attentional changes, especially in the High AQ group.

One final alternative explanation that could account for CPT-related performance alterations is changes in the size of the spatial attentional spotlight or window. Like its physical namesake, the attentional spotlight is described as a moveable "beam" that can narrow or widen its focus in order to facilitate the processing of visual stimuli (Eriksen & Yeh, 1985; Posner, 1990). Previous work suggests that children with ASC exhibit impairments with broadening the attentional spotlight. This was demonstrated on a task where children had to determine whether the vertical or horizontal line in a crosshair was longer. ASC children were slower and less accurate than TD children when responding to crosshairs that were larger than the crosshair presented immediately prior (Mann & Walker, 2003), with the authors suggesting that ASC is associated with a deficit in the ability to broaden the spatial spread of attention. This is consistent with the conclusions drawn from a meta-analysis of global/local processing studies on ASC which indicated that global processing is slowed in ASC (Van der Hallen et al., 2015).

By this logic, it is possible that the High AQ participants in Chapter Four did not as readily broaden their attentional spotlights given the opportunity. For example, prior to CPT training, High AQ participants’ faster reaction times during local categorization may be partly accounted for by a superior ability to maintain a small
attentional spotlight when shifting between the small fixation cross and the Navon figure. In contrast, Low AQ participants may have automatically widened the spotlight in response to the larger Navon figure, slowing their ability to efficiently categorize the local level of the Navon figure. This might also indicate that the capture of attention in Low AQ individuals by bottom-up or stimulus-driven mechanisms is stronger than what is seen for High AQ individuals. However, this account remains uncertain since similar group differences in baseline RT were not present for participants who completed CCT. Furthermore, would increasing the size of the fixation cross facilitate performance for global categorization in High AQ individuals? Presumably, a wider fixation cross would "prime" the attentional spotlight to a more appropriate size for processing the global level of the Navon figure, compensating for deficits in the ability to broaden the attentional spotlight. These possibilities are clearly worth investigating in future studies.

It is possible that CPT training may further broaden the size of the attentional spotlight, explaining why global interference increased for the High AQ group following CPT training, but did not change for the Low AQ group. The findings reported by Degutis and Van Vleet (2010) could also be explained if CPT increased the size of the spatial attentional spotlight: rather than increasing relative RH activation of neglect patients and inducing a 'leftward' attentional shift on a landmark task, training could allow more of the landmark stimulus to be attended to, including the previously neglected left-side. However, it is unlikely that the anodal stimulation effects arising for High AQ participants in Chapter Five can be accounted for by a similar widening of the attentional window, given that a wider window would allow for a greater amount of the stimulus to be attended to and should therefore reduce pseudoneglect. Further, there is no documented overlap between the brain region stimulated in Chapter Five, the right PPC, and regions that are noted to become more active due to CPT-related attentional demands (Bartolomeo, 2014; Corbetta & Shulman, 2002; Singh-Curry & Husain, 2009; Sturm & Willmes, 2001; Thiel, Zilles, & Fink, 2004).

In sum, it appears that CPT is a useful tool that can modulate attention in such a manner that the global level of Navon figures is more salient. However, there remains several gaps in our understanding with respect to the training paradigm. For example, it is uncertain the extent to which speeded responses or correctly inhibited responses during CPT enhances global attentional biases. Furthermore, it is unclear whether CPT directly facilitates global processing, or if changes in global attentional biases are a secondary effect from other modulations, such as a widening of the attentional
spotlight. It is also necessary to determine whether CPT can enhance attention to other globally-organized visual stimuli for High AQ and ASC individuals. For example, could the training paradigm improve the speed at which High AQ individuals process facial expressions (English, Maybery, & Visser, 2017), or impair performance on the EFT (Cribb et al., 2016)? It is clear that substantially more investigation is required to understand the mechanisms and potential of this training task.

The findings reported in Chapter Five provide interesting new insights into the results of a similar study conducted by Loftus and Nicholls (2012). These authors administered anodal tDCS over the right PPC of an unselected neurotypical sample but observed no changes in pseudoneglect on a greyscales task. They accounted for this outcome by suggesting that baseline RH activation in their sample was already high, limiting the ability to further activate this region. However, an alternative explanation arises from the fact that their unselected sample presumably contained a mix of High and Low AQ participants. It is possible that anodal tDCS altered pseudoneglect in the High AQ subset without affecting the majority of Low AQ participants who likely had already-high levels of right PPC activation. As AQ scores are known to be normally distributed in the general population (Baron-Cohen et al., 2001; Hoekstra, Bartels, Verweij, & Boomsma, 2007), is likely that a low proportion of High AQ participants in the sample tested by Loftus and Nicholls (2012) resulted in no significant effects being detectable.

Regarding the absence of cathodal tDCS effects, one possibility is that cathodal stimulation is simply insufficient to overcome relatively high baseline levels of RH activation. Similar failures to obtain effects following cathodal stimulation have been previously noted (for a review, see Jacobson, Koslowsky, & Lavidor, 2012), and it would appear that systematic changes following anodal and cathodal stimulation should not necessarily be expected given the interaction between a multitude of competing factors, including stimulation duration, location and intensity, as well the complexity of the task (Vallar & Bolognini, 2011). Regardless, it would be worth conducting a follow-up study in which cathodal tDCS is administered to the left PPC in an attempt to increase pseudoneglect in High AQ individuals. Theoretically, cathodal tDCS is unlikely to affect the distribution of spatial attention for Low AQ individuals given that the left PPC is relatively less active for this group and the present finding suggesting that anodal tDCS further stimulating the dominant right PPC also did not result in attentional shifts. However, given that the balance of left and right PPC activation appears not to favour the right PPC as strongly for High AQ individuals as it
does for Low AQ individuals, it is more likely that a leftward shift in attention for a High AQ group may result from left PPC cathodal tDCS. Should this prediction be correct, it would provide converging evidence for atypical hemispheric lateralization of spatial attention in High AQ individuals.

It is encouraging that two different techniques used on two different attentional tasks were at least partially successful at modulating spatial attention bias in High AQ participants, essentially ‘reducing the gap’ between their attentional profile and that of Low AQ participants. These outcomes suggest that the RH is responsive to different methods of activation, and relatively malleable in its activation levels. While there is clearly a need for further exploration regarding the possible effects of CPT training, especially with respect to its effect on behaviours linked to autism, it is nonetheless apparent that even a single session of CPT is sufficient to increase biases towards global levels in a High AQ sample. Furthermore, given that global processing is associated with the RH (Evans, Shedden, Hevenor, & Hahn, 2000; Flevaris, Bentin, & Robertson, 2010; Hübner & Studer, 2009; Lux et al., 2004; Malinowski, Hübner, Keil, & Gruber, 2002; Volberg & Hübner, 2004; Weissman & Woldorff, 2005; Yamaguchi, Yamagata, & Kobayashi, 2000) and understood to be slowed in ASC (Van der Hallen et al., 2015), it is possible that tDCS may be used to enhance attendance to globally-arranged stimuli well.

Implications for ASC and Future Directions

While the findings presented within this thesis further our understanding of spatial attention and hemispheric activation in individuals with High AQ, and by extension ASC, they are also not without limitation and future research will certainly be necessary to explore the limits of results obtained here. The most obvious constraint is that these studies used Low/High AQ comparisons, rather than neurotypical/ASC comparisons, and therefore the results do not directly inform the mechanisms underlying clinical cases of autism. While it will be necessary to confirm the present findings in an autistic sample, previous attention-related work has shown similar patterns of results in studies that recruited Low/High AQ and neurotypical/ASC comparison groups (e.g. performance on the EFT (Cribb et al., 2016; Horlin, Black, Falkmer, & Falkmer, 2014)) and thus there is no immediate reason to expect that the present results from High AQ participants would not also be found for a clinical ASC sample. Though the techniques used in Chapters Four and Five were successful with a High AQ group, one could question whether a clinical ASC group might be resistant to such interventions, potentially due to the greater severity of their symptomology.
However, this suggestion is countermanded by the fact that CPT and tDCS techniques have both been successful at invoking leftward shifts in attention for RH-lesioned patients (Degutis & Van Vleet, 2010; Sparing et al., 2009). In fact, if anything, stronger modulation effects may be obtained with an ASC sample because individuals with ASC should have lower baseline levels of RH activation compared to High AQ individuals.

Assuming pseudoneglect is also reduced (or absent) for individuals with ASC, it is possible that methods of observing the lateralization of spatial attention, such as the greyscales or landmark tasks, may hold some diagnostic value, especially as they are relatively affordable and simple to administer. While by no means diagnostic on its own, some consideration could be made as to whether such tasks should be included in the clinicians ‘toolbox’, alongside other attentional tests like the Block Design test and the EFT, that can potentially detect reduced attendance to the coherent, global structure. Similarly, reduced (or absent) pseudoneglect on the greyscales task could indicate the likely presence of social difficulties, given that a correlation was found between levels of pseudoneglect and the social skills factor of the AQ in Chapter Two and in the combined analysis reported in this chapter. This notion is not too dissimilar to how tasks that index attentional lateralization are used to detect diagnose left hemispatial neglect, which also commonly results following RH damage (Costa, Vaughan, Horwitz, & Ritter, 1969; Gainotti, Messerli, & Tissot, 1972; Heilman, 1995).

However, further examination of the greyscales task, and others tasks that index lateralization of spatial attention, is needed to check their reliability and validity and their association with AQ scores and ASC status. It is especially important that biases in attention for ASC children receive further investigation. While tasks like line bisection have been reported to show decreasing levels of pseudoneglect across the lifespan (Jewell & McCourt, 2000), there has been limited research on how attentional biases for non-face stimuli may change across the developmental period with respect to ASC. This gap in the literature could be filled with the incorporation of attentional lateralization tasks into longitudinal studies examining infants at risk of ASC (e.g., infants with an autistic sibling) as they progress through childhood.

One obvious limitation of the results reported in Chapters Four and Five is that the attentional modulations following increased RH activation are observed for relatively abstract stimuli that are limited in their real-world ecological validity. Whether these activation techniques could alter attentional performance for face perception, for example, remains to be seen, and is a logical ‘next step’ in this line of investigation. For example, can the otherwise reduced leftward attentional bias for
faces in ASC individuals (Dundas, Best, et al., 2012; Guillon et al., 2014) be increased using either of these methods, similar to how anodal tDCS increased pseudoneglect in the High AQ group in Chapter Five? Additionally, as a reduced preference for globally-organized visual stimuli is associated with impairments in face identity and emotion recognition in ASC (Behrmann et al., 2006; Gross, 2005), it follows that increased activation of global processing regions in the RH could benefit face processing in ASC individuals. Given the present findings, it is feasible that individuals with ASC would stand to benefit from techniques like CPT and tDCS that result in greater RH activation, improving their ability to interpret facial cues. Furthermore, as the ability to process faces accurately and efficiently is essential for successful social interactions (Dawson et al., 2005), it is possible that such interventions would ultimately lead to increases in general social functioning – a highly desirable outcome with respect to ASC.

It is also important to investigate how long the performance modulations arising from CPT and tDCS last, as any potentially therapeutic value that these techniques might have is likely to depend on the durability of their effects. Regarding CPT, it is difficult to determine how long training effects should be expected to last. The study by Van Vleet et al. (2011) found that the benefits from a single session of CPT were observable for approximately 5-10 minutes, whereas the effects observed in the replication study in Chapter Four lasted the entire duration of the post-training period (approximately 12 minutes). Further complicating matters is the study by Degutis and Van Vleet (2010), in which CPT was administered 36 minutes/day for nine days before attentional changes on a landmark task were observed. While the RH-damaged patient’s left neglect remained ameliorated during the day immediately following the end of the CPT training regimen, neglect had returned by the next follow-up period which was 14-days post-training. This means that training effects lasted anywhere between 1 and 13 days. Furthermore, as a longer training period may have been necessary to induce training effects in the latter study of RH-lesioned patients, and as RH deficits may also be present in ASC for spatial processing, inducing attentional changes in ASC individuals may also require relatively longer periods of CPT than what was administered to the Low/High AQ participants in Chapter Four. The limited extent of the training may account for why only partial training effects were observed in the High AQ group post-CPT. A more comprehensive set of training effects may have been elicited with prolonged, repeated training sessions, as per Degutis and Van Vleet’s (2010) methodology.
Substantially more research exists regarding the effects of tDCS, and studies demonstrate that the after-effect of stimulation is generally longer lasting than for the equivalent period of CPT, especially when tDCS is delivered repeatedly and with greater intensity (for a review, see Paulus, Antal, & Nitsche, 2013). As with CPT, the amount of tDCS required to produce observable changes in attention and the duration of these changes may be different for ASC individuals relative to neurotypical individuals. Unfortunately, very few studies have administered tDCS to ASC participants (Amatachaya et al., 2014, 2015; D’Urso et al., 2014; Hupfeld & Ketcham, 2016), and none of these, to my knowledge, have stimulated the PPC or explored tDCS-related effects on spatial attention. Several studies have found that cathodal tDCS administered to the dorsolateral prefrontal cortex is associated with positive outcomes on measures of autistic behaviours (Amatachaya et al., 2014, 2015; D’Urso et al., 2014). For example, multiple sessions of tDCS administered over a period of several weeks resulted in positive changes in social and health/behaviour domains as measured by the autism treatment evaluation checklist (Amatachaya et al., 2015; Geier, Kern, & Geier, 2012). Furthermore, another study concluded that, although there are some difficulties, administering tDCS to children with ASC is feasible and capable of inducing long-lasting behavioural changes (Hupfeld & Ketcham, 2016). These reports, together with the findings in the present thesis, suggest that the field of ASC could stand to benefit from further exploration of the potential therapeutic use of tDCS.

It should also be noted that a large portion of the present thesis discusses spatial attention of High AQ individuals with respect to behavioural evidence for reduced RH lateralization of spatial attention and associated attentional changes. While behavioural evidence can be a good indicator of the relative activation of specific brain regions, it is still limited by the fact that it is only an indirect measure of hemispheric activation. As such, attempts should be made to confirm that actual differences in hemispheric activation map on to the behavioural measures used in the present thesis in the expected directions. The use of neuroimaging techniques, like functional magnetic resonance imaging and near-infrared spectroscopy, could assist with answering several pertinent questions. For example, neuroimaging could be used to confirm that High AQ individuals show relatively reduced RH activation during the greyscales task and probe which brain regions are more active when engaging in CPT relative to CCT. The answers to such questions are necessary to further our understanding of the precise mechanisms that underlie the attentional differences and training effects reported in the present thesis.
Final thoughts

In summary, the primary aims of this thesis were to provide novel evidence that High AQ individuals have reduced RH activation that results in abnormal lateralization of spatial attention, and to explore how techniques that activate the RH could modulate these attentional shifts. The present research highlights a relatively novel aspect of attention (pseudoneglect) that reduces as a function of increasing levels of autistic-like traits, which may be useful for detecting atypical lateralization of spatial attention in ASC. Furthermore, this research also demonstrates that attentional differences between Low and High AQ individuals can be reduced using both indirect (CPT) and direct (tDCS) methods of RH activation, and that these techniques might also be applied to other aspects of visual attention, such as face perception.

It is my sincere hope that aspects of the research presented in this thesis may one day be used to help design new methods of early intervention for children with ASC. As stated several times throughout this thesis, it is possible that the RH-activating properties of CPT and tDCS have the potential to increase activation of regions responsible for global processing, which in turn is closely associated with face processing ability. If reduced RH activation for spatial attention in ASC ultimately contributes to impaired facial processing, and consequently social functioning, then encouraging greater use of the RH at early ages may result in improved outcomes in these areas. For example, taking the key components that underlie RH activation following CPT and embedding them into a game that a child can play several times a week may encourage and strengthen activation of RH regions responsible for accurate and efficient face processing, and short tests assessing lateralization of attention could provide a quick assessment of the impact of CPT training. Although such a scenario is currently a distant goal, the studies presented within this thesis take several strides towards achieving such a reality.

References


